THE EXTENDED GAIN HYPOLE ANTENNA: AN APPLICATION OF COMPUTER MODELING TO ANTENNA DESIGN.

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THESIS

THE EXTENDED GAIN HYPOLE ANTENNA :
AN APPLICATION OF COMPUTER MODELING
TO ANTENNA DESIGN

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The Extended Gain Hypole Antenna : An Application of

Computer Modeling to Antenna Design

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from the

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The Hypole is an experimentally developed hybrid dipole antenna for use in land mobile and shipboard communication systems. It employs a unique feed system to provide isolation from the degrading effects of a limited ground plane. This results in an increase in performance over an end-fed half-wave dipole similarly employed.

Since the Hypole acts as a half-wave dipole isolated from ground, the possibility of improving its performance by the addition of a second properly phased half-wavelength element exists. A design approach using a thin wire antenna computer program was selected over the more tedious trial-and-error procedures on an experimental development. The validity of a computer model of the Hypole antenna was verified experimentally. This model served as the basis for designing the extended gain Hypole antenna, which when built provided a 2.7 db gain over the Hypole. This study demonstrates the successful application of the computer modeling approach to antenna design.

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I. THE HYPOLE ANTENNA

The unbalanced Hypole antenna is a vertically polarized hybrid dipole antenna designed for application in landmobile and shipboard communication systems. The Hypole antenna is essentially a half wavelength vertically polarized antenna positioned above and isolated from the ground plane. Its feed system provides isolation from the ground plane, and matches its impedance to the characteristic impedance of the attached coaxial cable.

The Hypole antenna consists of a main radiating element which is approximately three quarters of a wavelength long and an additional quarter wavelength stub located in its near field. Both elements are mounted vertically on a small RF "shorting plate" which may then be raised over the finite ground plane. The unbalanced Hypole antenna is shown in figure 1-1.The Hypole antenna was designed to overcome some of the difficulties experienced when operating a vertical antenna over a limited ground plane, such as one encounters in roof-top vehicular installations at VHF and UHF frequencies.

The important properties of an antenna are its directional characteristics, gain and impedance. These properties are strictly related. An unmatched antenna reflects back some of energy and can cause problems at the generator. The radiation pattern is also very important since the direction and beam width of the main lobe of radiation affects the performance of a mobile communication system.

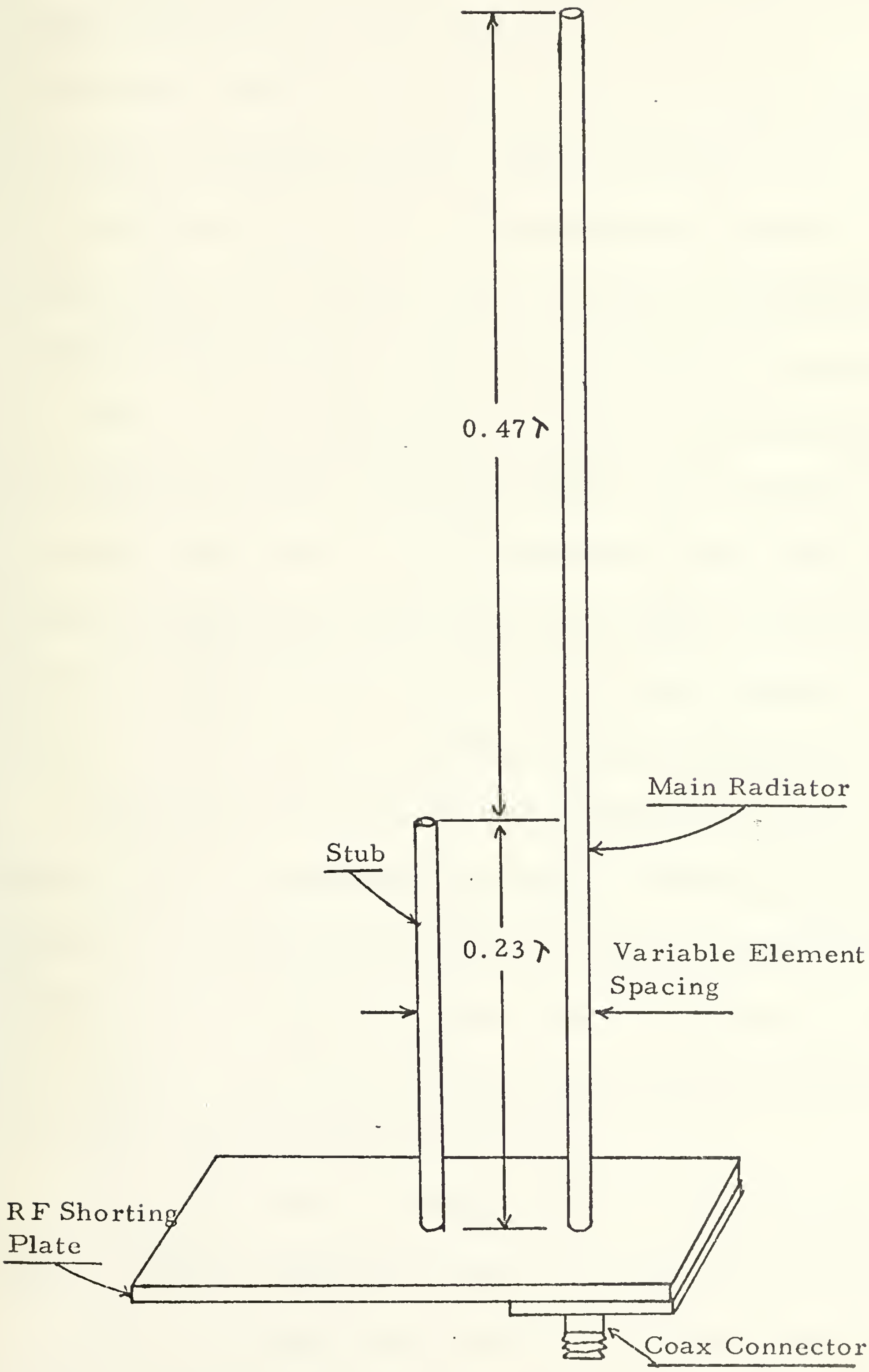


Figure 1-1
The Hypole Antenna

Theoretically a one quarter wavelength monopole on an infinite ground plane and a half wavelength dipole in free space are equivalent. Measurements however show that this is not true for a one quarter wavelength monopole over a limited size ground plane (approximately one square wavelength in size). Measured gains of -5 to -10 DB along the horizon with respect to a reference dipole are typical, although not widely publicized. This huge "loss" in gain can be attributed to the "cutback" in pattern shape occurring in the plane of the ground system. To produce strong radiation on the horizon requires ground plane currents flowing for many, many wavelengths away from the antenna, a condition which clearly cannot be met with a small ground plane. The effects of flatness and losses of the ground plane can be minimized in some installations but it is not usually possible to obtain a "large enough" ground plane for vehicular or marine installations.

The Hypole antenna has great advantages over a one quarter wavelength monopole in practical installations. Impedance matching is simple to accomplish and the structure exhibits significant gain in the radiation pattern along the grounded plane. This gain is accomplished by creating an antenna which is effectively isolated from the deteriorating (degrading) effects of the ground plane.

If an electrical half wavelength radiator is driven against a ground plane, it exhibits maximum voltage and minimum current at the feed point, thus a very high input impedance. The voltage and current distribution are shown in figure 1-2. Extending the radiator to three

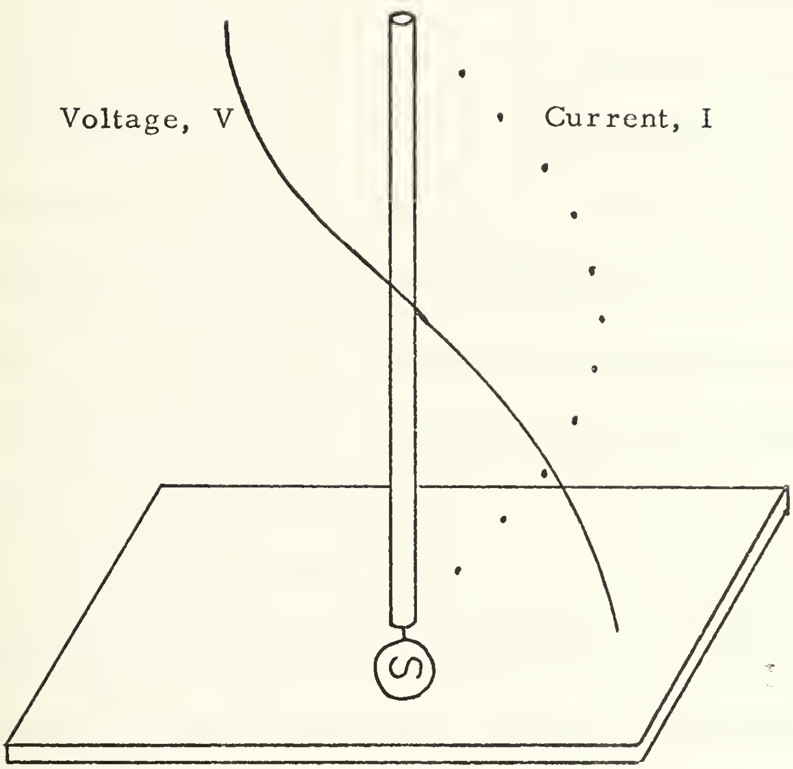


Figure 1-2
Voltage and Current Distribution
on a Halfwave Radiator

quarters wavelength results in a low input impedance which provides a good working value of impedance but the radiation pattern is undesirable for mobile communications. See figure 1-3 and figure 1-4.

To cancel this undesirable lobing effect, another element which is one quarter wavelength is placed in the near field of the main radiator on a RF shorting plate. This element is fed out-of-phase with the main element. Since these elements are parallel, the field established by the out-of-phase current in the quarter-wave section cancels the field of the lower end of the three quarters wavelength radiator and only the top half wavelength of the main element will radiate without cancellation. This section produces the desirable radiation characteristics of a one half wavelength dipole. Figure 1-5 shows the expected current distribution on a hybrid dipole.

A usable input impedance is obtained by using the quarter wavelength section as a quarter wave transformer where the high input impedance of the half wavelength radiating section can be transformed to a much lower value. The formula for this transformation is:

$$Z_{IN} = \frac{Z_0^2}{Z_L} \tag{1-1}$$

Where Z_L is the impedance of the radiating section and Z_0 is the characteristic impedance of the transformer section. According to parallel wire transmission line principles, the characteristic impedance of the quarter wave section can be determined by selecting the diameter and spacing of the two elements.

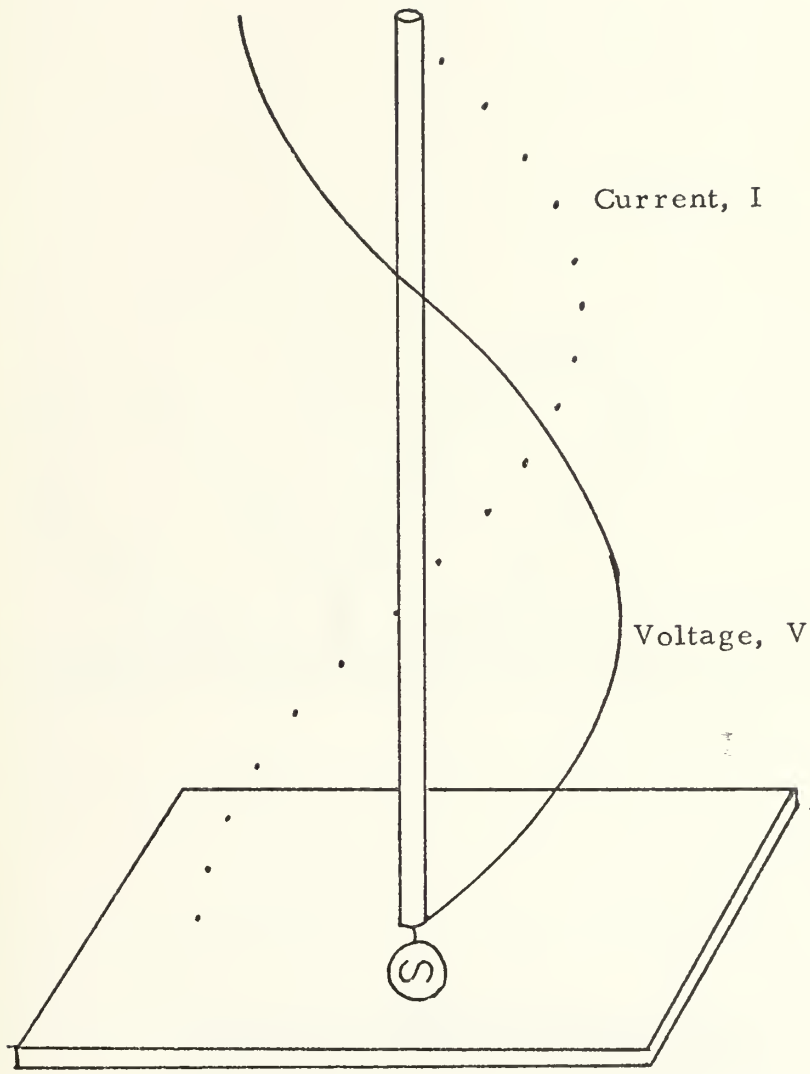


Figure 1-3
Voltage and Current Distribution on a
Three Quarter Wavelength Radiator

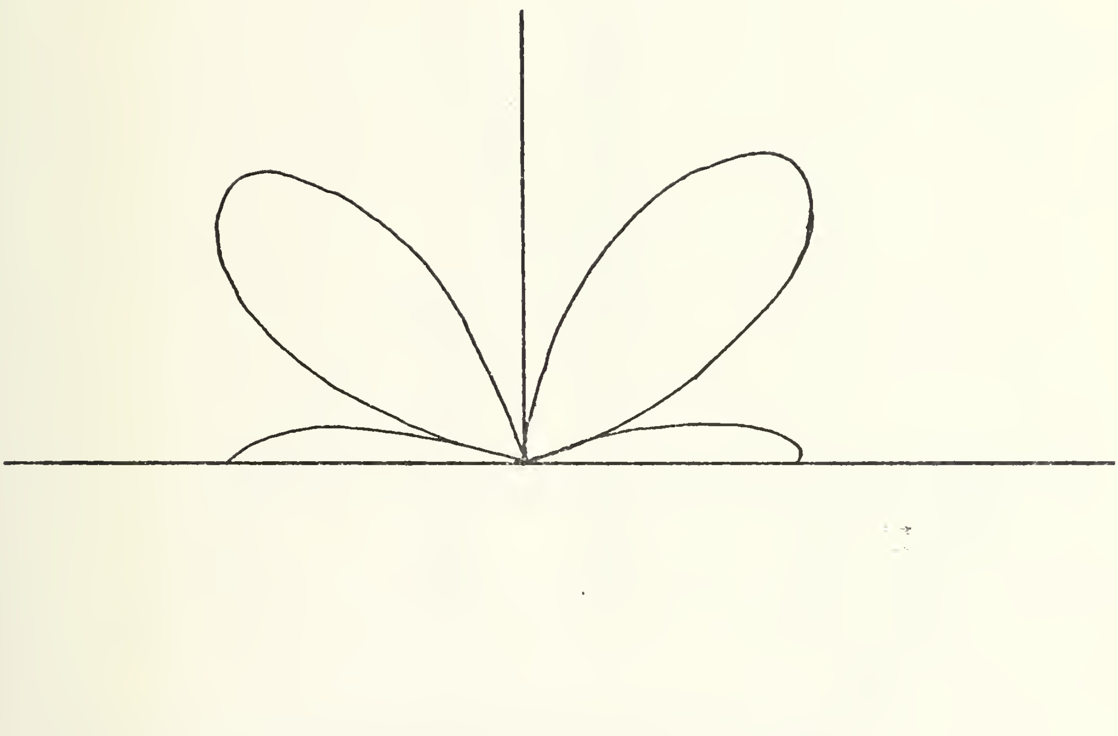


Figure 1-4
Elevation Radiation Pattern of the
Three Quarter Wavelength Monopole

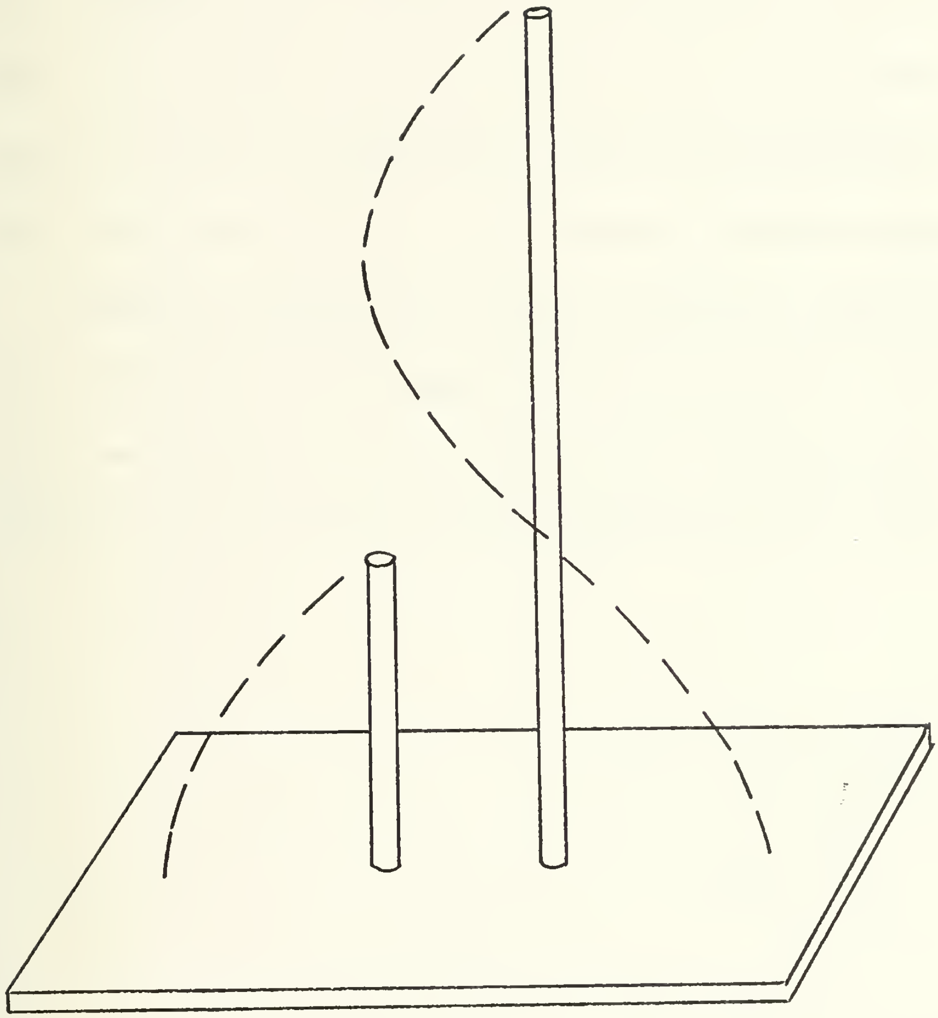


Figure 1-5
Current Distribution on the Hypole

$$Z_0 = 276 \operatorname{Log}_{10} \frac{B}{A} \qquad (1\text{-}2)$$

where B is the spacing between the two elements and A is the radius. By varying the spacing B, Z_0 can be changed, and according to equation 1-1 a matched input impedance can be obtained at the feed point. Although these relationships cannot be applied directly to the Hypole antenna because of reactive discontinuities, they do illustrate that the input impedance of the antenna does vary as a function of element spacing.

Another advantage of the Hypole antenna for mobile and shipboard communications is its simple construction and ease of mounting. Construction details are shown in figure 1-6. A photograph of the 450 Mhz Hypole antenna used during this investigation may be seen in Appendix C.

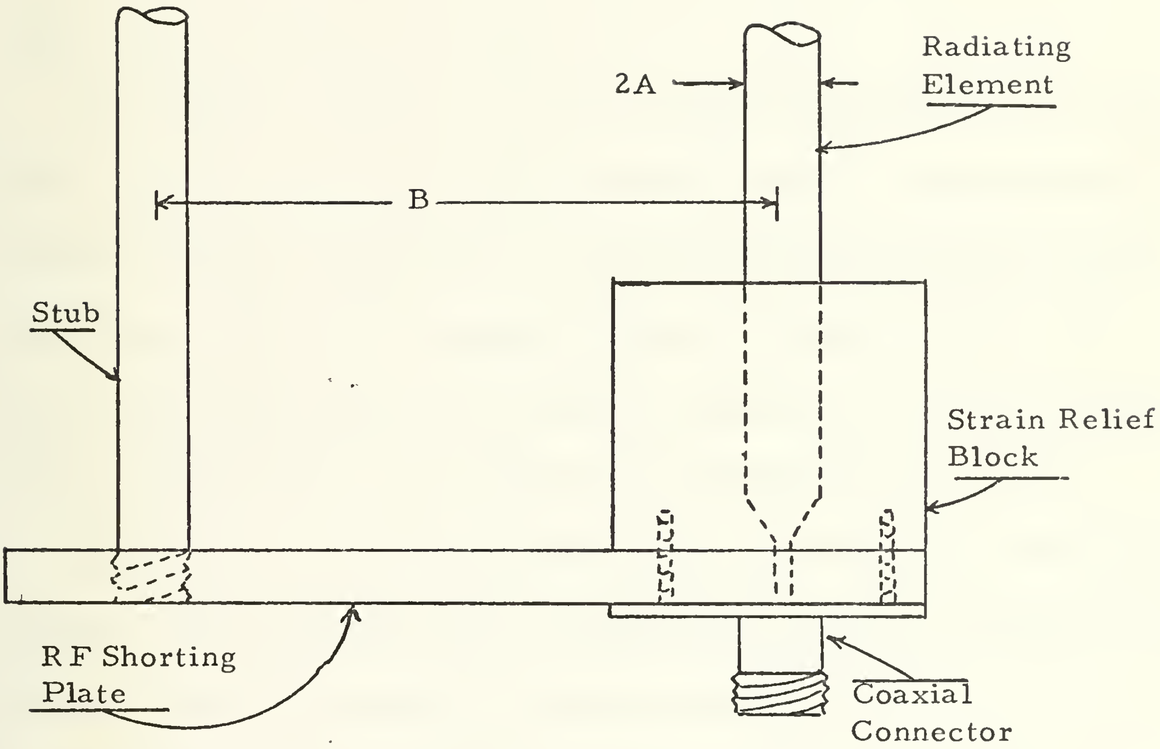


Figure 1-6
Construction Details of a Hypole

II. MODELING THE HYPOLE ANTENNA

In order to gain an insight into the behavior of the Hypole antenna, a computer model of the antenna was developed. This model serves a dual purpose. It predicts the behavior of the existing Hypole antenna, and it serves as the basis for developing an "extended gain Hypole" antenna which will be discussed in Chapter IV.

The computer model, developed to analyze the performance of the Hypole antenna, makes use of the modified antennas-scatterers analysis program "ASAP" prepared by J. McCormack [2] at the Naval Postgraduate School. The ASAP program performs an analysis of thin-wire structures utilizing piecewise sinusoidal expansion for current distribution, as developed by J. H. Richmond [3] of Ohio State University.

Figure 2-1 represents the model used for the analysis of the Hypole antenna. This model provides meaningful data on the performance of the Hypole antenna operating over a finite ground plane.

Using the criteria presented by Shaw [1], an unbalanced Hypole designed for 450 Mhz operation was modeled. The element lengths for the unbalanced Hypole antenna are 0.7 and 0.23 wavelengths. For a 450 Mhz antenna this corresponds to lengths of 46.67 and 15.33 centimeters respectively.

A comparison of the results obtained from the model and experimental data obtained from antenna measurements indicates that a correction

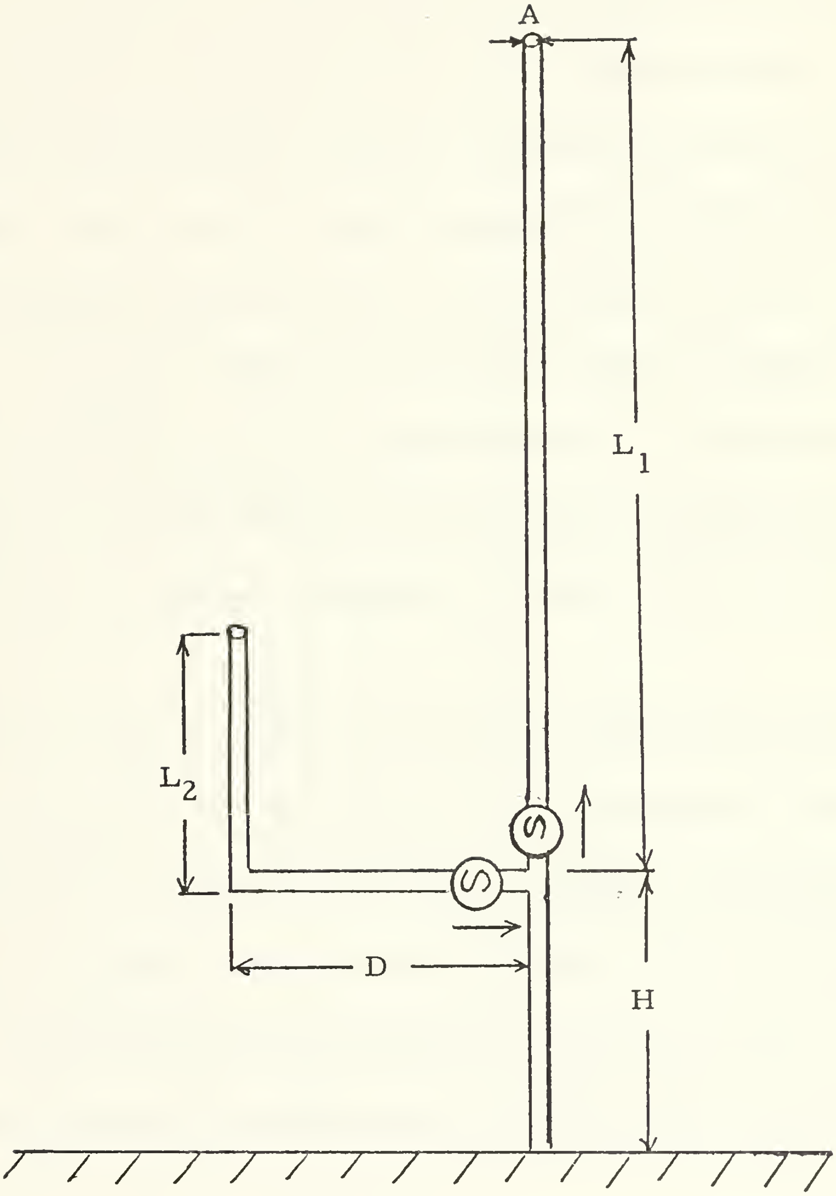


Figure 2-1
Computer Model of the Hypole Antenna

L_1 = Length of the Main Radiating Element

L_2 = Length of Stub

D = Element Spacing

H = Height Above the Ground Plane

A = Diameter of Elements

factor should be added to the basic model. This correction factor is a function of element spacing and increases with a decrease in element separation. For an element spacing of one inch (0.038 λ) a correction factor of two percent was found to give more meaningful results. An element spacing of one half inch (0.019 λ) required a correction factor of four percent. The correction factor is applied by increasing the lengths of the elements in the model over the physical element lengths of the antenna. Figures 3-2 thru 3-12 show the effects of varying the model correction factor on antenna input impedance. A summary of calculated antenna input impedances as a function of element spacing, height above the ground plane and model correction factor is located in Appendix A.

The model developed for the Hypole antenna yields the far field pattern shown in figure 2-2. The maximum field strength is in the direction of the shorter of the two antenna elements. The quarter wavelength element, therefore, acts as a weak director. The minimum field strength was calculated to be 1.35 decibels below the maximum value. Far field plots obtained from experimental measurements closely follow this pattern.

Field strength measurements obtained experimentally show the gain of the Hypole to be slightly less than that obtained from a half-wave reference dipole in free space, but the field strength obtained using the computer model is greater than that obtained from the model of a half-wave dipole in free space. Using the ASAP program the average power

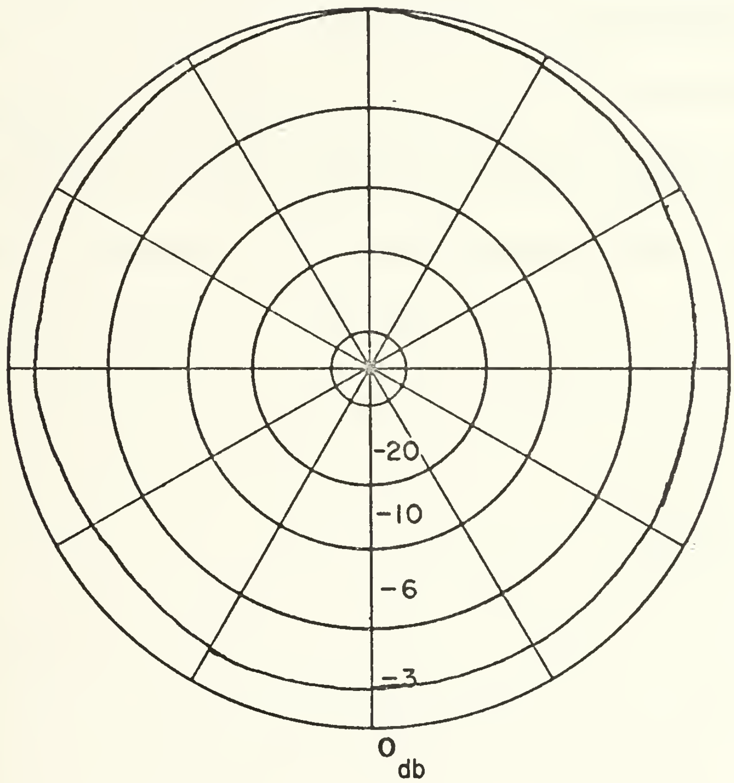


Figure 2-2
Far Field Radiation Plot of Hypole Antenna
Pattern in Horizontal Plane

gain of a half-wave dipole in free space was found to be 1.65 which corresponds to a 2.17 DB gain over that of an isotropic radiator. The Hypole antenna had an average power gain of 2.717 or a 4.34 DB gain over the isotropic radiator. The difference in the power gain between the calculated and measured values can be attributed to the effects of the limited ground plane associated with the physical Hypole antenna.

The computer model developed for the Hypole antenna has been shown to be very effective in predicting the input impedance of the Hypole antenna as a function of element spacing and operating frequency. The program also accurately predicts the shape of the far field radiation pattern, but it is limited in its ability to predict field strength.

III. HYPOLE ANTENNA-COMPARISON OF EXPERIMENTAL AND PREDICTED DATA

An unbalanced Hypole antenna designed for operation at 450 Mhz was constructed using criteria presented by Shaw [1]. The antenna was assembled from one eight inch diameter copper coated steel rods. The length of the main radiating element is 46.67 centimeters (0.7 λ) and the length of the second element is 15.33 centimeters (0.23 λ).

The antenna was designed to facilitate changes in element spacing and height above the ground plane. Figure 1-6 shows the construction details of the antenna used.

The input impedance of the Hypole antenna was the first parameter measured. The input impedance as a function of element spacing and height above the ground plane was measured using the experimental set up shown in figure 3-1. The vector voltmeter provides the amplitude and phase relationship of the reflected voltage. The reflected voltage coefficient is related to the input impedance of the antenna and the characteristic impedance of the feed line by the equation

$$K_V = \frac{Z_{IN} - Z_0}{Z_{IN} + Z_0} \tag{3-1}$$

where Z_{IN} is the input impedance of the antenna and Z_0 is the characteristic impedance of the feed line.

The input impedance of the antenna can be found either by solving equation 3-1 or by plotting the magnitude and phase information provided

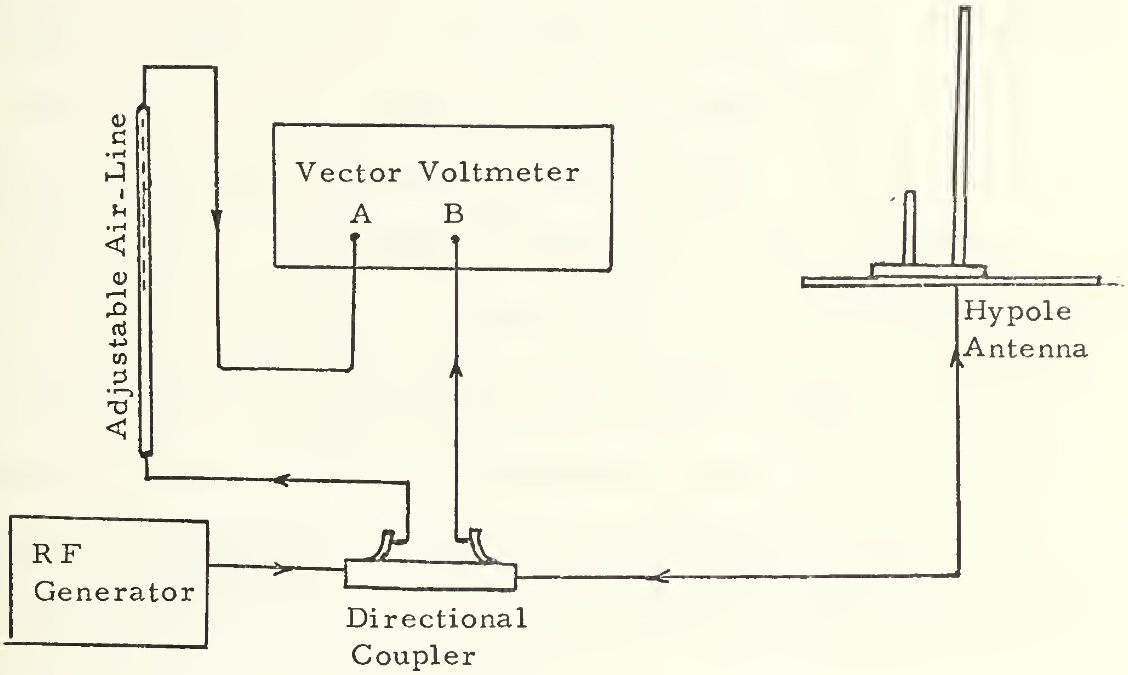


Figure 3-1
Experimental Setup for Input Impedance Measurement

by the vector voltmeter on a Smith chart. The graphical solution was used to obtain experimental data used in this report. The characteristic impedance of the feed line used was 50 ohms.

Input impedance measurements were taken with the Hypole antenna at a height of 6 inches (0.23 λ) and 8 inches (0.30 λ) above the ground plane. This is the normal configuration of the Hypole which provides isolation from the effects of the limited ground plane. Element spacing of one inch (0.038 λ) and one half inch (0.019 λ) were investigated. Figures 3-2 thru 3-9 illustrate the relationship between the experimentally obtained data and that predicted by the computer model. It is observed that a correction factor of two percent is required to match the experimental and computer data for an element spacing of one inch, and a four percent correction factor is required when the element spacing is reduced to a half inch.

The need for including a correction factor results from the thin wire structure assumed by the ASAP computer program. The finite size of the elements becomes more of an influential factor as the elements are brought closer together.

As shown by equations 1-1 and 1-2 of Chapter 1, the input impedance of the Hypole antenna is a function of element spacing. The computer model developed for the Hypole antenna provides an accurate and convenient way to predict the input impedance as a function of the geometry of the antenna and its operating frequency.

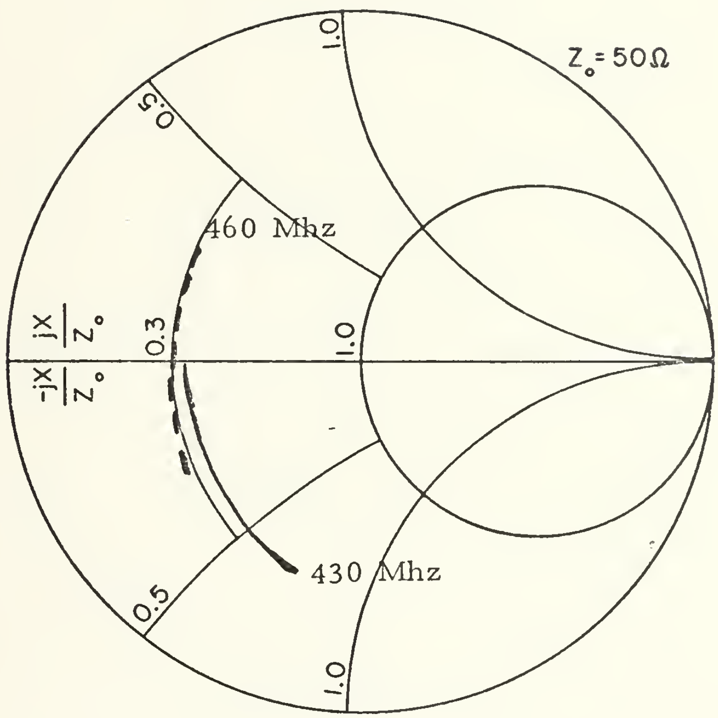


Figure 3-2
Input Impedance of Hypole
Height Above the Ground Plane 6 Inches
Element Spacing One Half Inch
No Model Correction Factor
Measured Values: Broken Curve
Calculated Values: Solid Curve

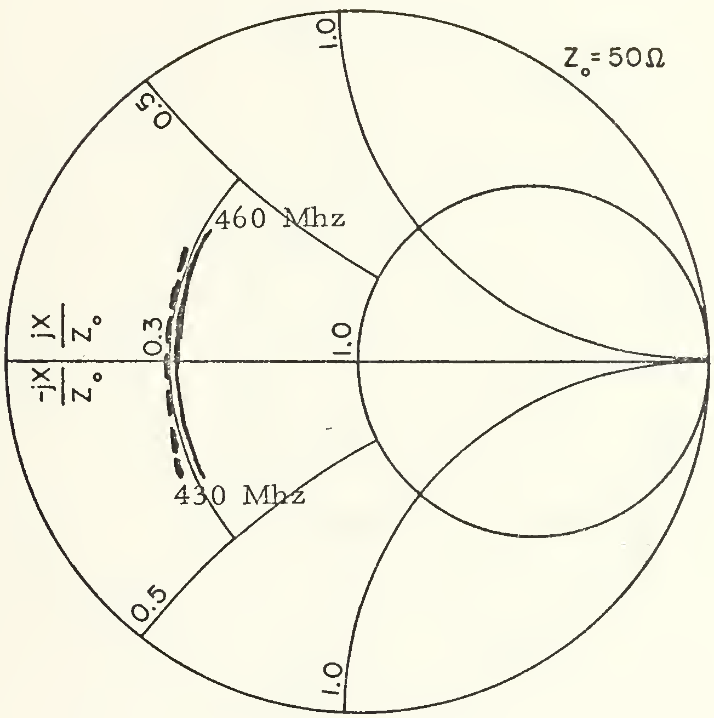


Figure 3-3
Input Impedance of Hypole
Height Above the Ground Plane 6 Inches
Element Spacing One Half Inch
4% Model Correction Factor
Measured Values: Broken Curve
Calculated Values: Solid Curve

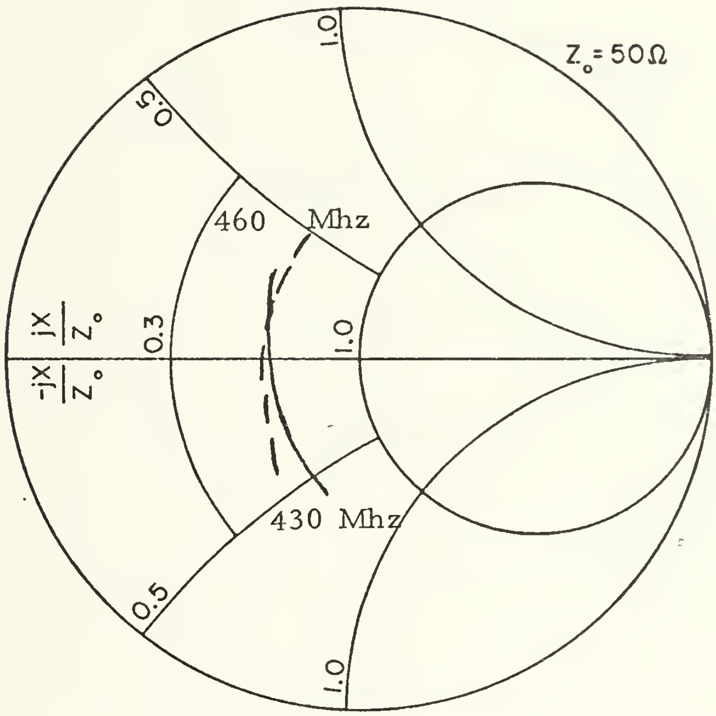


Figure 3-4
Input Impedance of Hypole
Height Above the Ground Plane 6 Inches
Element Spacing One Inch
No Model Correction Factor
Measured Values: Broken Curve
Calculated Values: Solid Curve

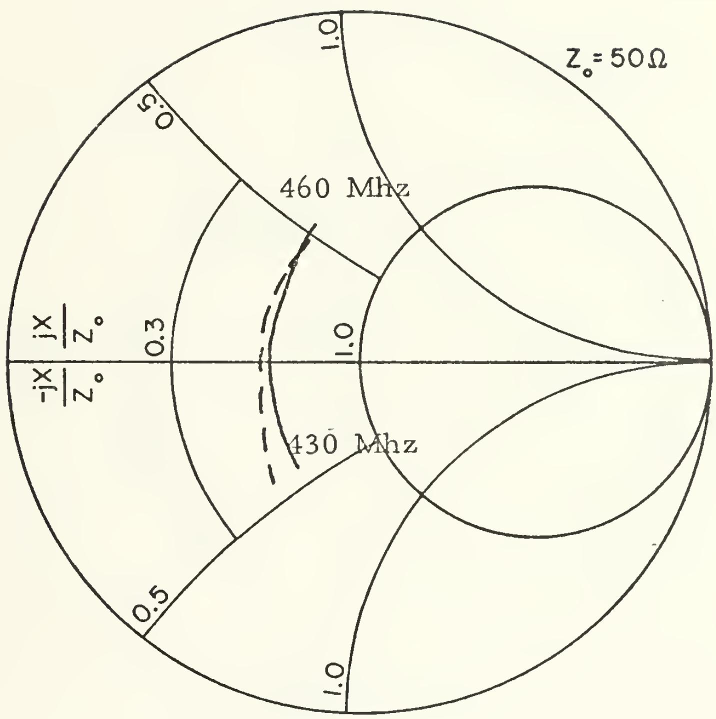


Figure 3-5
Input Impedance of Hypole
Height Above the Ground Plane 6 Inches
Element Spacing One Inch
2% Model Correction Factor
Measured Values: Broken Curve
Calculated Values: Solid Curve

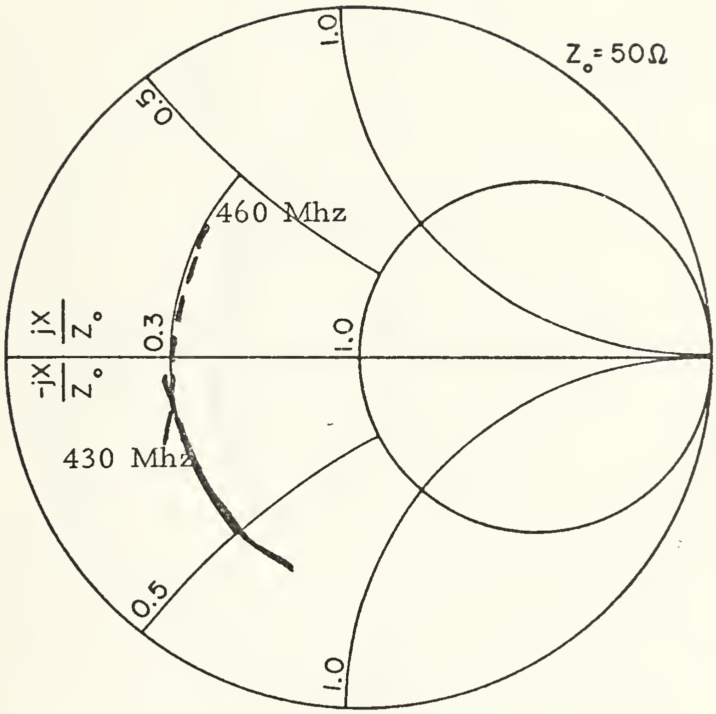


Figure 3-6
Input Impedance of Hypole
Height Above the Ground Plane 8 Inches
Element Spacing One Half Inch
No Model Correction Factor
Measured Values: Broken Curve
Calculated Values: Solid Curve

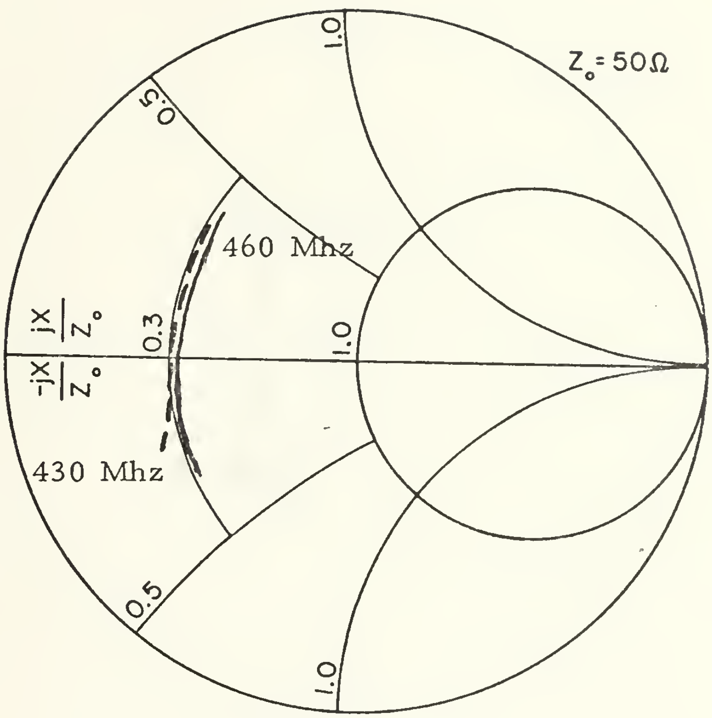


Figure 3-7
Input Impedance of Hypole
Height Above the Ground Plane 8 Inches
Element Spacing One Half Inch
4% Model Correction Factor
Measured Values: Broken Curve
Calculated Values: Solid Curve

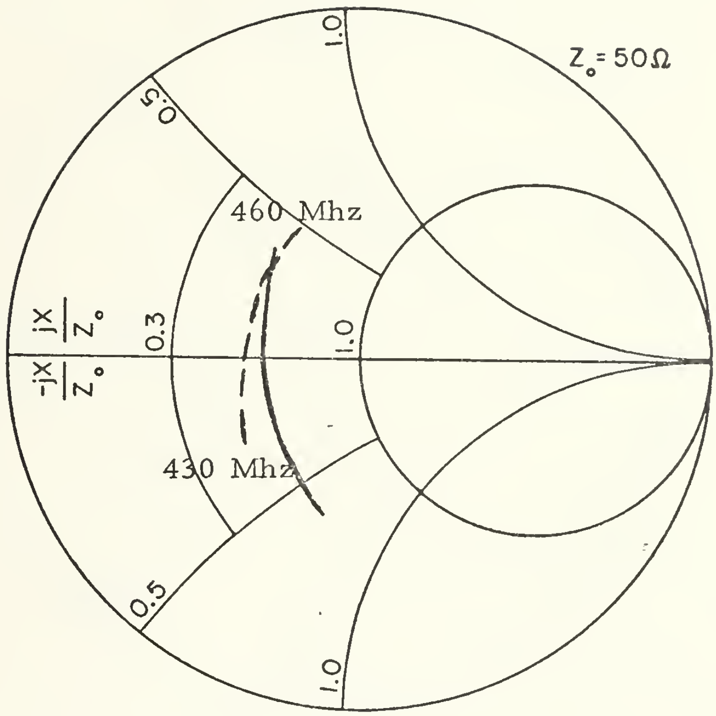


Figure 3-8
Input Impedance of Hypole
Height Above the Ground Plane 8 Inches
Element Spacing One Inch
No Model Correction Factor
Measured Values: Broken Curve
Calculated Values: Solid Curve

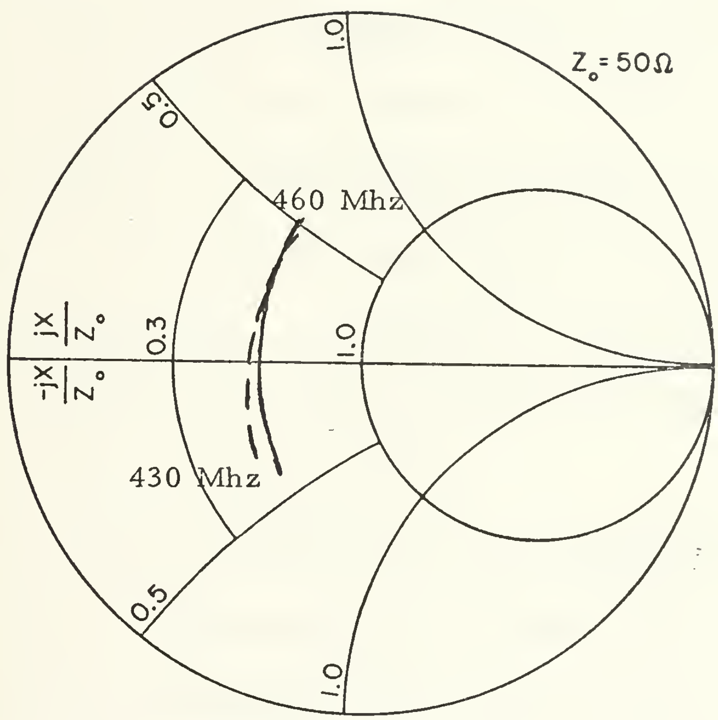


Figure 3-9
Input Impedance of Hypole
Height Above the Ground Plane 8 Inches
Element Spacing One Inch
2% Model Correction Factor
Measured Values: Broken Curve (Finite Ground)
Calculated Values: Solid Curve (Infinite Ground)

The effect of the limited ground plane on input impedance was investigated by placing the Hypole antenna on a ground plane. A 32 inch (1.22 λ) by 16 inch (0.61 λ) aluminum plate was used to simulate the finite ground plane used in mobile communication systems. Figures 3-10 thru 3-13 are plots of this data. It is once again observed that the correction factor previously determined enable the computer model to predict antenna input impedance of the finite ground plane.

The far field pattern of the Hypole antenna was obtained using the equipment arrangement shown in figure 3-14. In this arrangement the Hypole was used as a receiving antenna and a log-periodic as a transmitting antenna. The distance between the transmitting and receiving antennas was 100 feet (45 λ). The pattern was obtained by the Hypole antenna on its ground plane while recording the magnitude of the receiving signal by means of a pen recorder.

Figures 3-15 thru 3-18 are the far field plots for the Hypole antenna. The zero DB reference corresponds to the radiation pattern of a tuned dipole in free space. The reference dipole was tuned to a half-wavelength at 450 Mhz. and matched to the feed line. Although the Hypole was not matched to the feed line a correction factor based on the VSWR can be readily calculated.

When the antenna is placed on the ground plane a maximum loss of 3.5 DB with respect to the tuned dipole was observed for an element spacing of one half inch. This corresponds to an adjusted loss of 1.9 DB. The minimum field strength was recorded when the main element

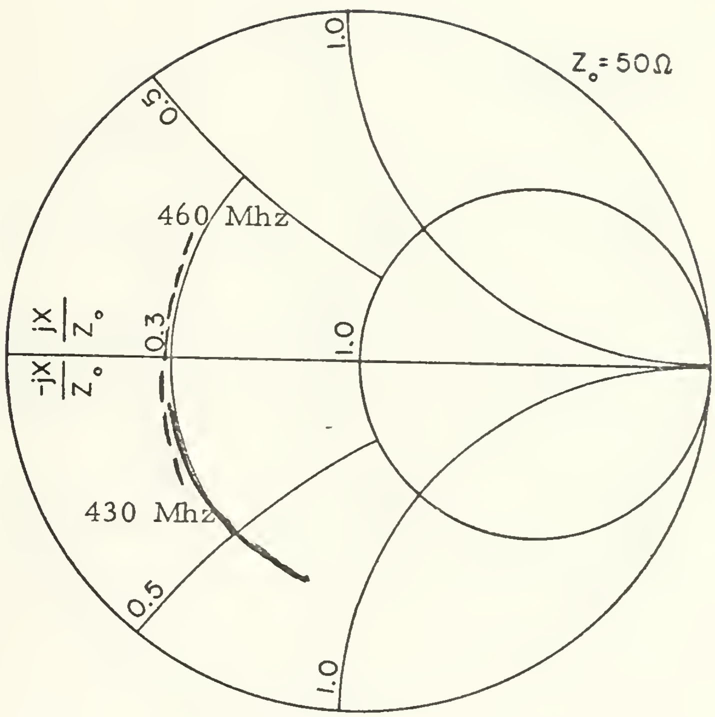


Figure 3-10
Input Impedance of Hypole on Ground Plane
Element Spacing One Half Inch
No Model Correction Factor
Measured Values: Broken Curve (Finite Ground)
Calculated Values: Solid Curve (Infinite Ground)

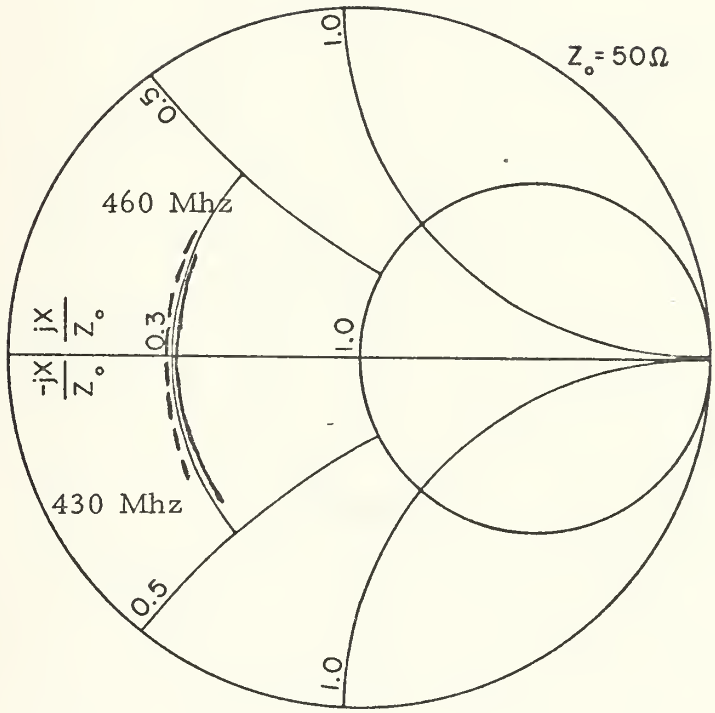


Figure 3-11
Input Impedance of Hypole on Ground Plane
Element Spacing One Half Inch
4% Model Correction Factor
Measured Values: Broken Curve (Finite Ground)
Calculated Values: Solid Curve (Infinite Ground)

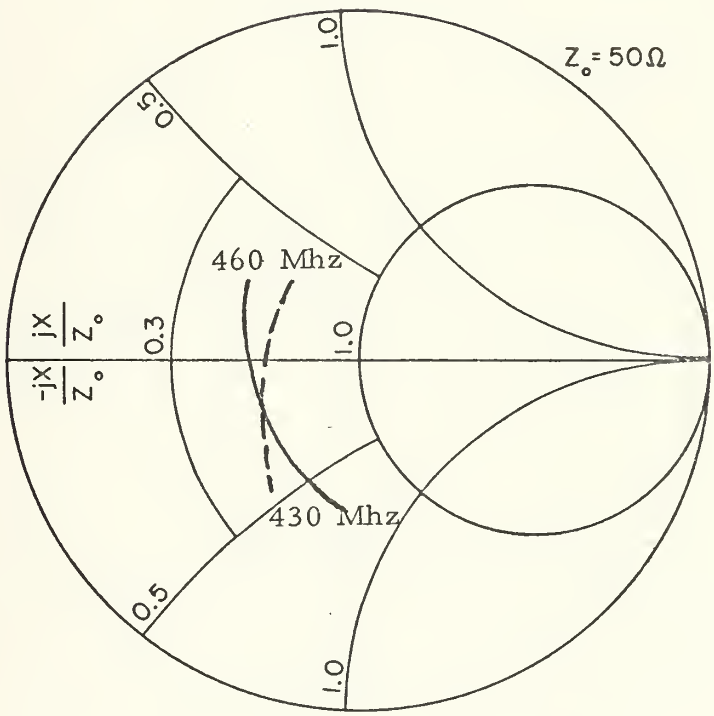


Figure 3-12
Input Impedance of Hypole on Ground Plane
Element Spacing One Inch
No Model Correction Factor
Measured Values: Broken Curve (Finite Ground)
Calculated Values: Solid Curve (Infinite Ground)

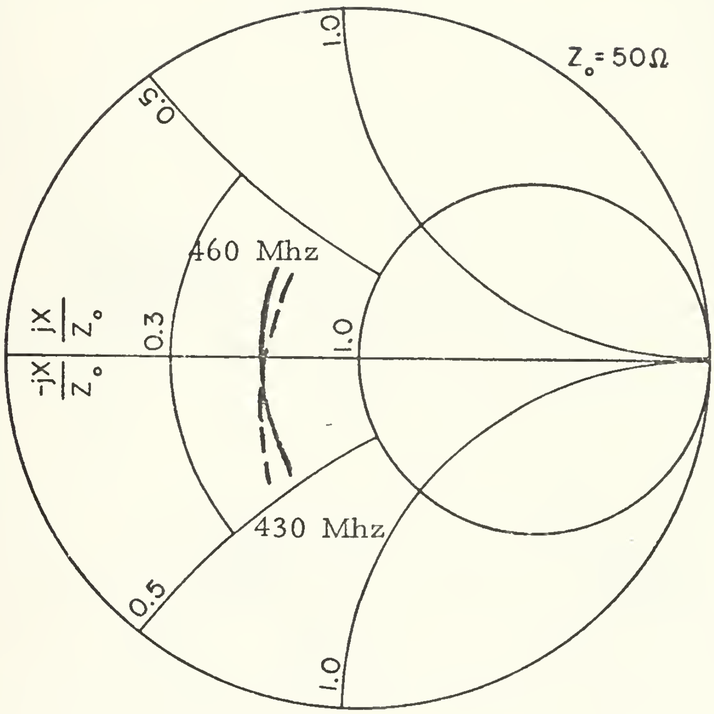


Figure 3-13
Input Impedance of Hypole on Ground Plane
Element Spacing One Inch
2% Model Correction Factor
Measured Values: Broken Curve (Finite Ground)
Calculated Values: Solid Curve (Infinite Ground)

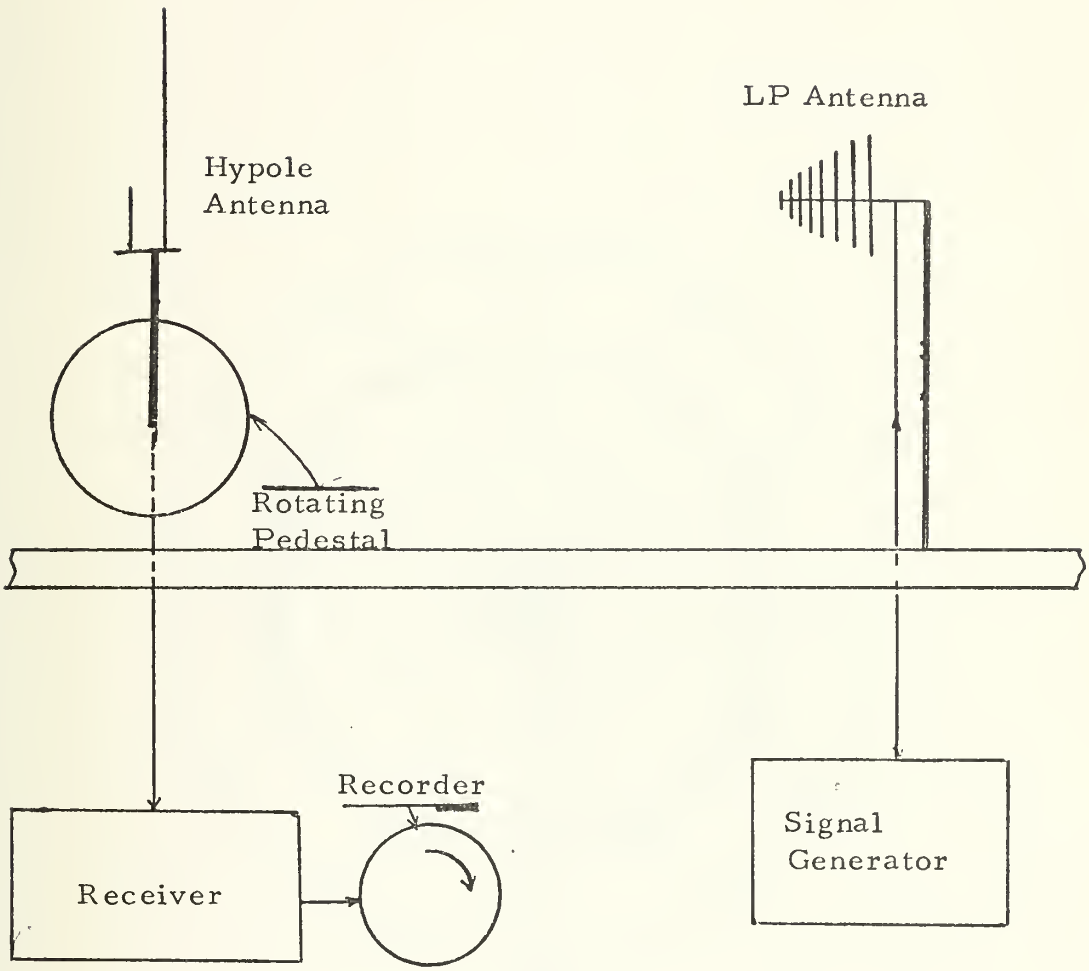


Figure 3-14
Experimental Setup for Pattern Measurements

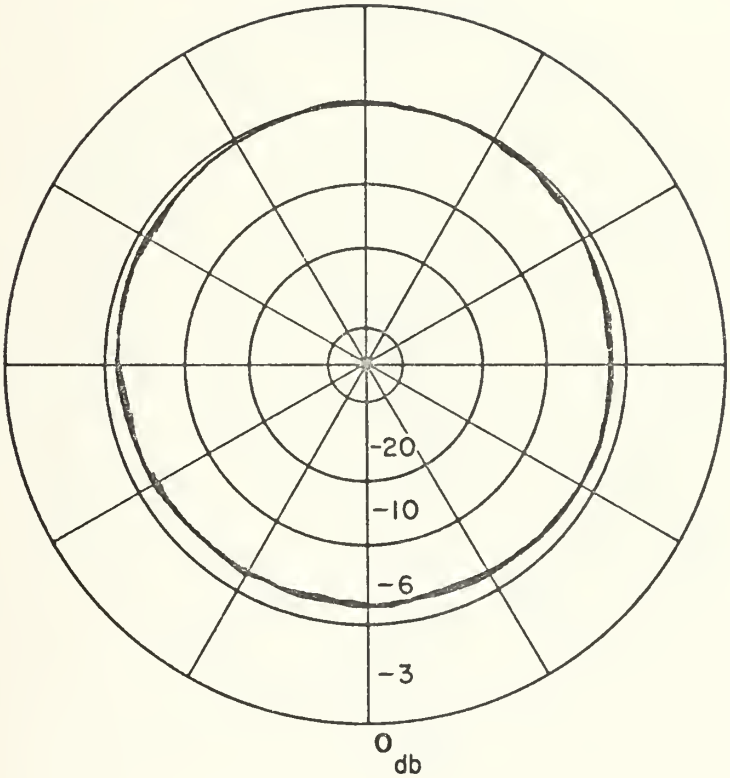


Figure 3-15
Measured Far Field Radiation Pattern
Hypole on the Ground Plane
Element Spacing One Half Inch

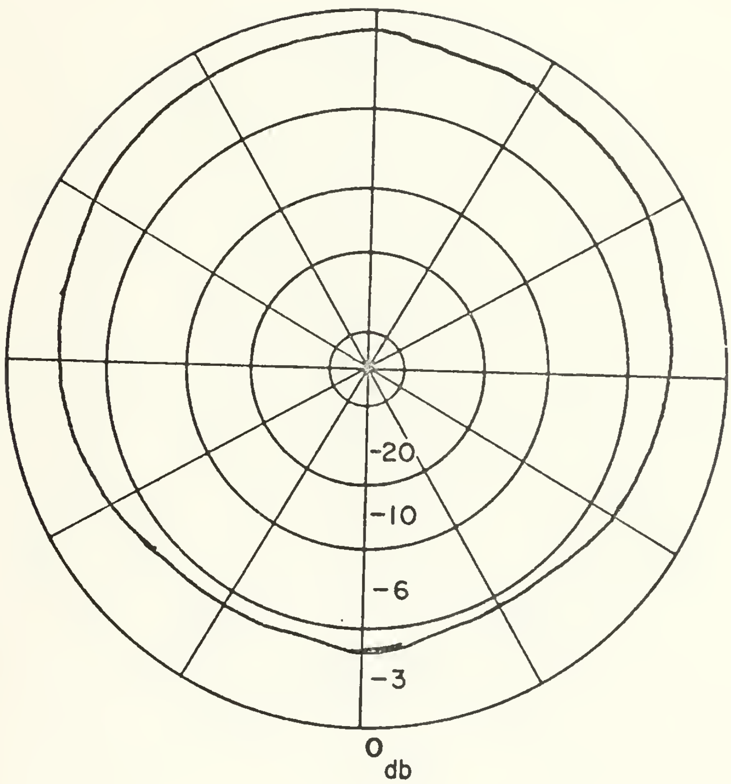


Figure 3-16
Measured Far Field Radiation Pattern
Hypole on the Ground Plane
Element Spacing One Inch

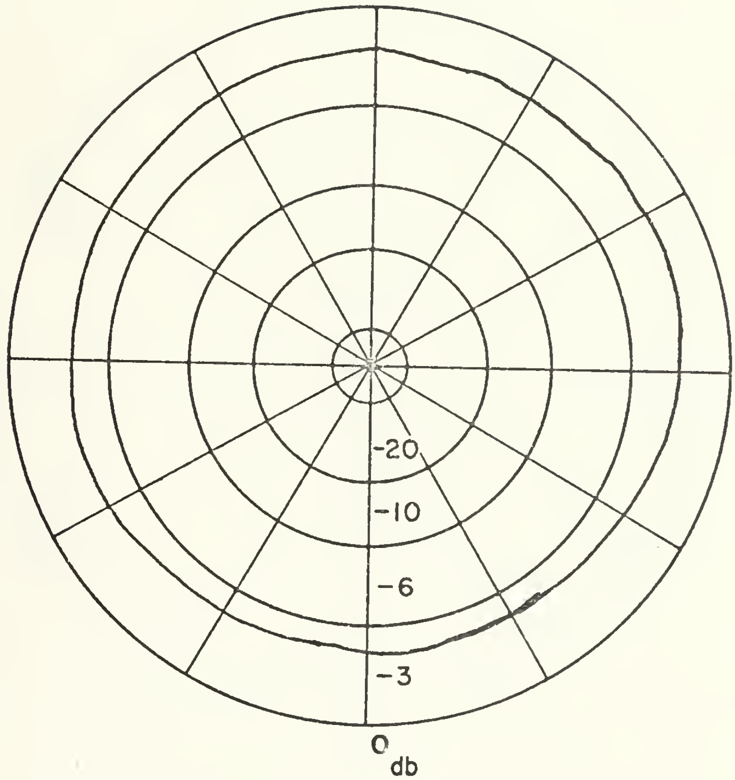


Figure 3-17
Measured Far Field Radiation Pattern
Hypole 8 Inches Above the Ground Plane
Element Spacing One Half Inch

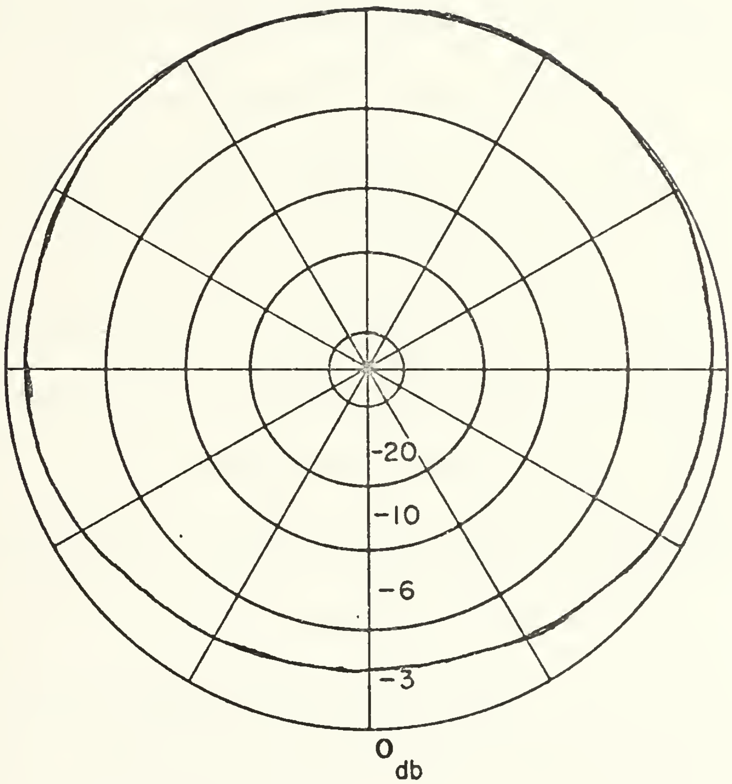


Figure 3-18
Measured Far Field Radiation Pattern
Hypole 8 Inches Above the Ground Plane
Element Spacing One Inch

of the antenna faced the illuminator. A dip of 2.5 DB (2.2 DB adjusted loss) was recorded for a one inch element spacing. It is seen in Figures 3-15 and 3-16, that the azimuth pattern is not circular, but corresponds to the shape predicted by the computer model (figure 2-2). Degradation of the omnidirectional pattern of the antenna is attributed to the degrading effects of the ground plane.

Azimuth radiation patterns obtained with the Hypole antenna located eight inches above the ground plane show an improvement in gain. Measurements for element spacings of one half inch and one inch showed that the maximum losses had been reduced to -2.0 DB and -0.5 DB. This corresponds to adjusted values of -0.65 DB and -0.05 DB respectively. Since the degrading effects of the limited ground plane were reduced, the azimuth pattern is more circular than it was on the ground plane. For a one inch element spacing the antenna gain was greater than that of the half-wave dipole when the quarter wave stub faced the illuminator. Figures 3-17 and 3-18 show azimuth radiation patterns when the hypole is raised eight inches above the ground plane. As seen in figure 3-18 a difference of 1.5 DB was recorded between the maximum and minimum far field strengths. This correlates well with the 1.35 DB difference predicted by the computer model.

IV. MODELING THE EXTENDED GAIN HYPOLE ANTENNA

The gain of a one wavelength end-fed antenna is not equal to twice that of a half-wavelength antenna because the currents in the two half-wavelengths are not in phase. By placing the proper value of reactance between the two half wavelengths a phase shift can be introduced which will cause the currents to be in phase, and the horizon gain of the antenna can thus be increased. Figure 4-1 shows the desired current distribution for this antenna.

The Hypole antenna gain is effectively that of a half-wave dipole located above the ground plane and isolated from it. The "extended gain Hypole antenna" places an additional half wavelength element on the Hypole antenna. By means of a properly selected reactive element placed between the two half wavelength elements the currents are effectively placed in phase with a resultant 3 DB maximum increase in gain for the antenna.

The extended gain Hypole antenna was designed using a coil to provide the necessary reactance. Figure 4-2 represents the model used for this antenna. The length of the added element was selected to be equal to the difference between the two elements of the original Hypole antenna. An additional seven centimeter section representing the length of the coil form was added to the model. The value of inductive reactance represented by the coil was placed at the center of the seven centimeter section

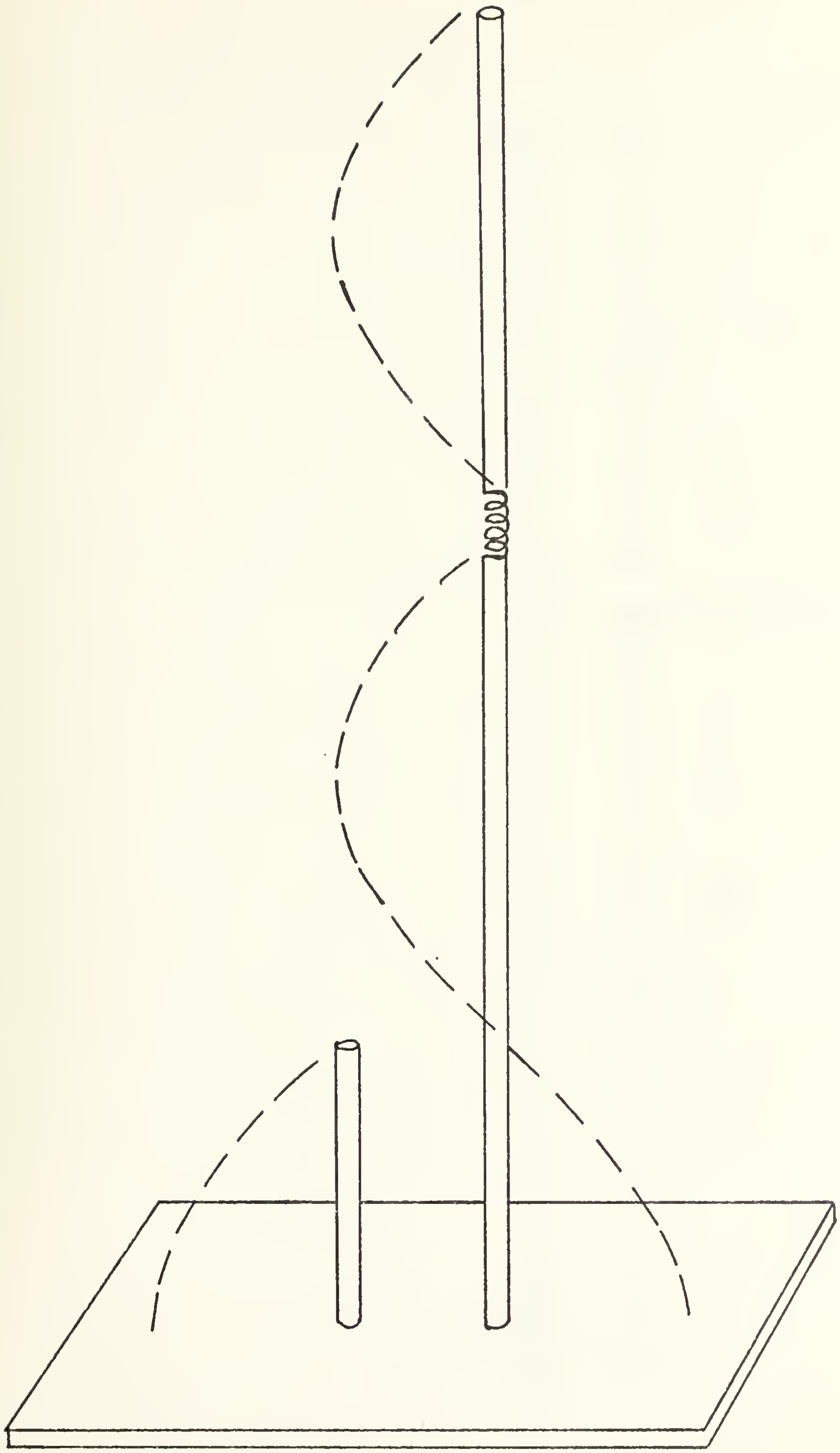


Figure 4-1
Current Distribution on the Extended Hypole

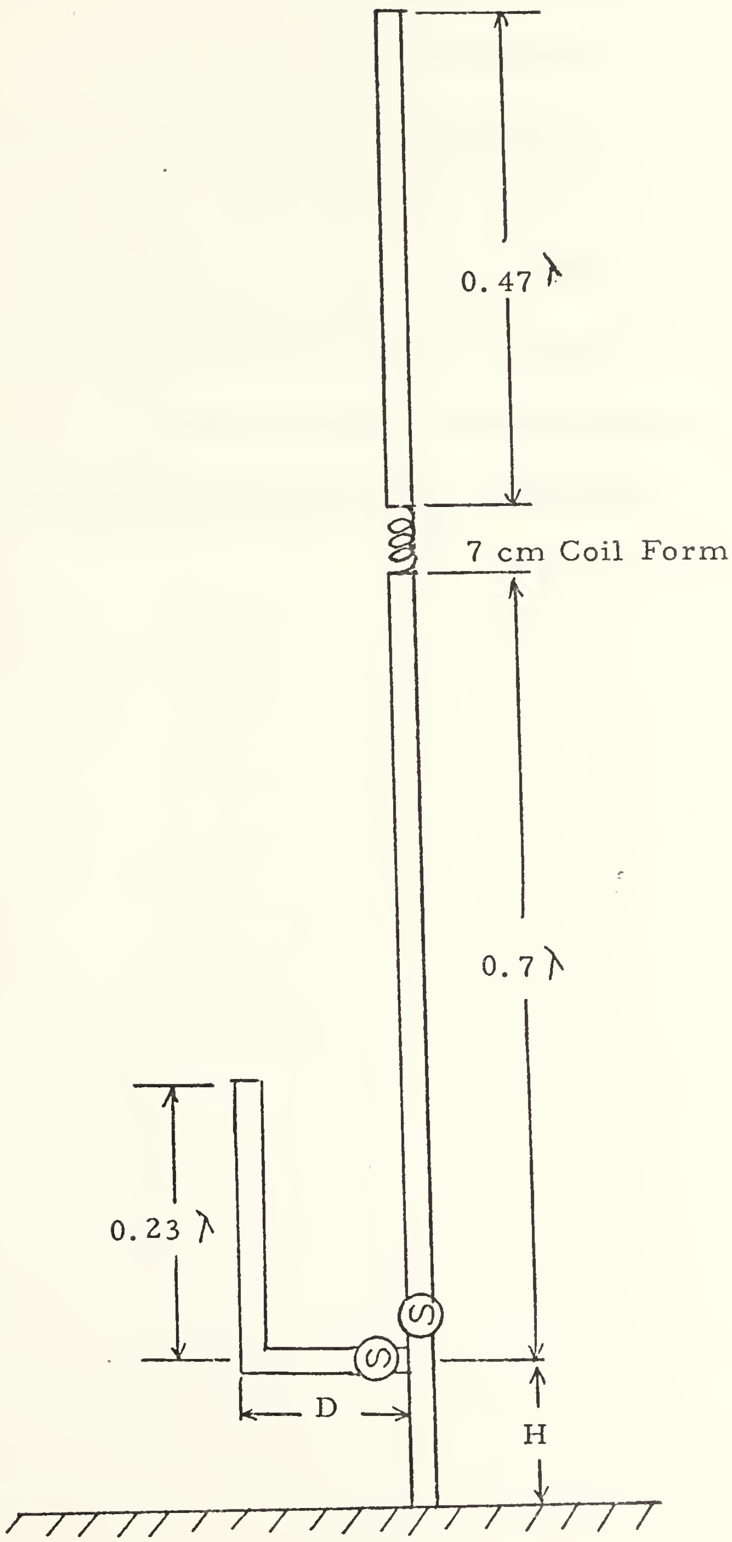


Figure 4-2
Model of the Extended Gain Hypole Antenna

within the program. The Hypole antenna model for a height above the ground plane equal to eight inches, (.3048 λ) and an element spacing of one inch (0.381 λ) was used as the basis for the extended Hypole antenna model. A listing of the ASAP cards used for both the Hypole and the extended gain Hypole models are described in Appendix B.

The inductive reactance was varied until the average power gain of the antenna was maximized at a value of 1.77 DB above the regular Hypole. The seven hundred ohms reactance required corresponds to an inductance value of 0.248 microhenries when operating at 450 Mhz. Table 4-1 summarizes the results of this investigation.

TABLE 4-1

GAIN VS. INDUCTIVE LOADING FOR EXTENDED GAIN HYPOLE

INDUCTIVE REACTANCE OHMS	INDUCTANCE MICROHENRIES AT 450 Mhz.	AVERAGE POWER GAIN	GAIN OVER HYPOLE, DB
600	.212	3.958	1.63
620	.219	4.008	1.69
640	.226	4.044	1.73
660	.233	4.068	1.75
680	.241	4.080	1.77
700	.248	4.081	1.77
720	.255	4.075	1.76
740	.262	4.060	1.74
760	.269	4.038	1.72
780	.276	4.011	1.69
800	.283	3.980	1.66

V. EXTENDED HYPOLE COMPARISON OF EXPERIMENTAL AND PREDICTED DATA

An extended gain Hypole antenna was assembled. The construction details for this antenna are shown in figure 5-1 and by a photograph in Appendix C.

The inductance of the coil which is used to provide the necessary phase shift can be obtained by the relationship,

$$L = \mu_o N^2 LA \qquad (5-1)$$

where N is the number of turns per unit length, L is the length of the coil and A is the cross sectional area of the coil.

The value of inductance required by the extended gain Hypole is low, and small changes in the value of inductance used results in a significant drop in antenna gain. Care must, therefore, be exercised when winding the coil. Accurate values of inductance are obtained by varying the spacings of the coil turns while measuring the value of inductance. Potting of the finished coil is required to prevent changes of inductance from occurring.

An azimuth radiation pattern of the extended Hypole was obtained using the equipment arrangement shown in figure 3-14. Since maximum gain was obtained for the regular Hypole antenna with a 1 inch element spacing and the height above the ground plane equal to 8 inches, this configuration was selected as the starting point for investigation of the extended Hypole antenna. First the azimuth radiation pattern of the Hypole was plotted as

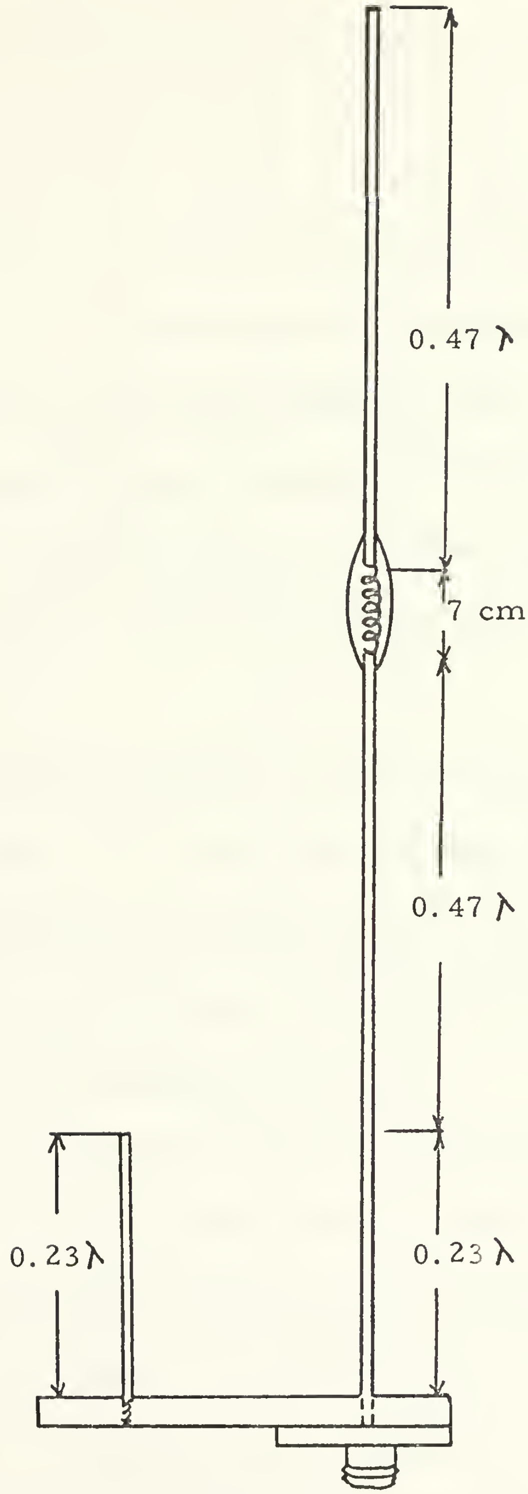


Figure 5-1
The Extended Hypole Antenna

a reference. Then the Hypole was extended and the azimuth radiation pattern of the extended Hypole was obtained for various values of inductance. At 450 Mhz. a 0.24 microhenry inductor results in an average gain of 2.8 DB with respect to the Hypole antenna. This corresponds to an adjusted value of 2.7 DB. The value of the inductance that provides the greatest increase in gain is the same as that predicted by the computer model. Figure 5-2 is a comparison of the extended Hypole antenna with a half-wave tuned dipole and a regular Hypole antenna. Figure 5-3 shows the predicted and measured gain of the extended Hypole over the regular Hypole for various values of inductance. The extended Hypole gives an average gain of 1.5 DB (1.7 DB adjusted gain) over the half-wave tuned dipole.

For a 0.5 inch element spacing, using a 0.22-0.24 microhenry inductance, an average gain of 2.7 DB (2.6 DB adjusted) over the Hypole was recorded. The maximum gain obtained with 0.5 inch element spacing is less than that for a 1 inch spacing. Figure 5-4 shows the azimuth radiation pattern for the 0.5 inch element spacing.

A limited size ground plane affects not only gain as discussed in Chapter IV but also the shape of the azimuth radiation pattern. The influence of the ground plane geometry on pattern shape was investigated by orienting the plane of the antenna elements along the larger and the smaller centerlines. The orientation of the antenna with respect to the ground plane influenced the antenna pattern as is shown in figure 5-5 and 5-6.

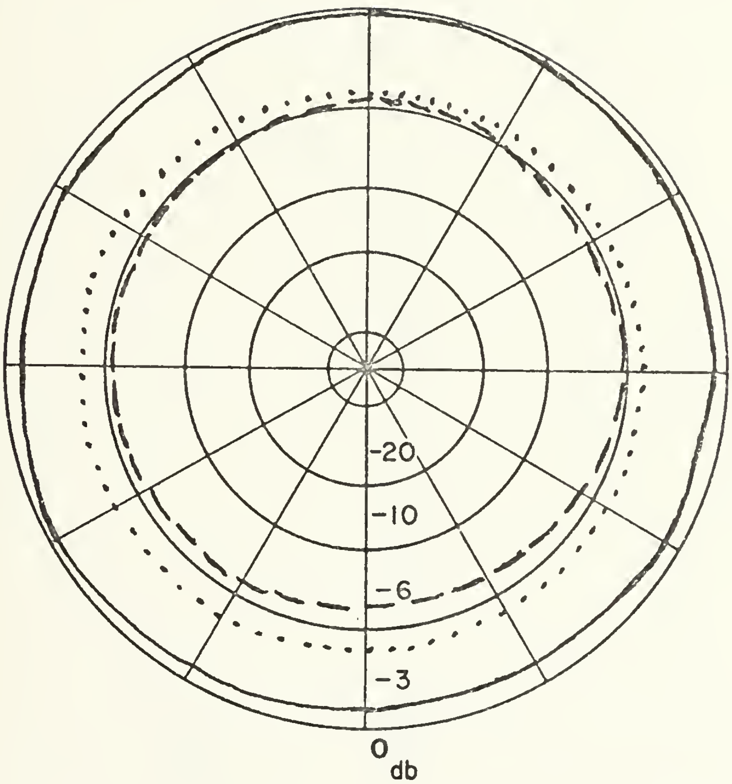


Figure 5-2
Far Field Radiation Pattern
Height Above the Ground Plane 8 Inches
Element Spacing One Inch
Extended Gain Hypole : Solid Curve
Half-Wave Dipole (Free Space) : Dotted Curve
Hypole Broken Curve

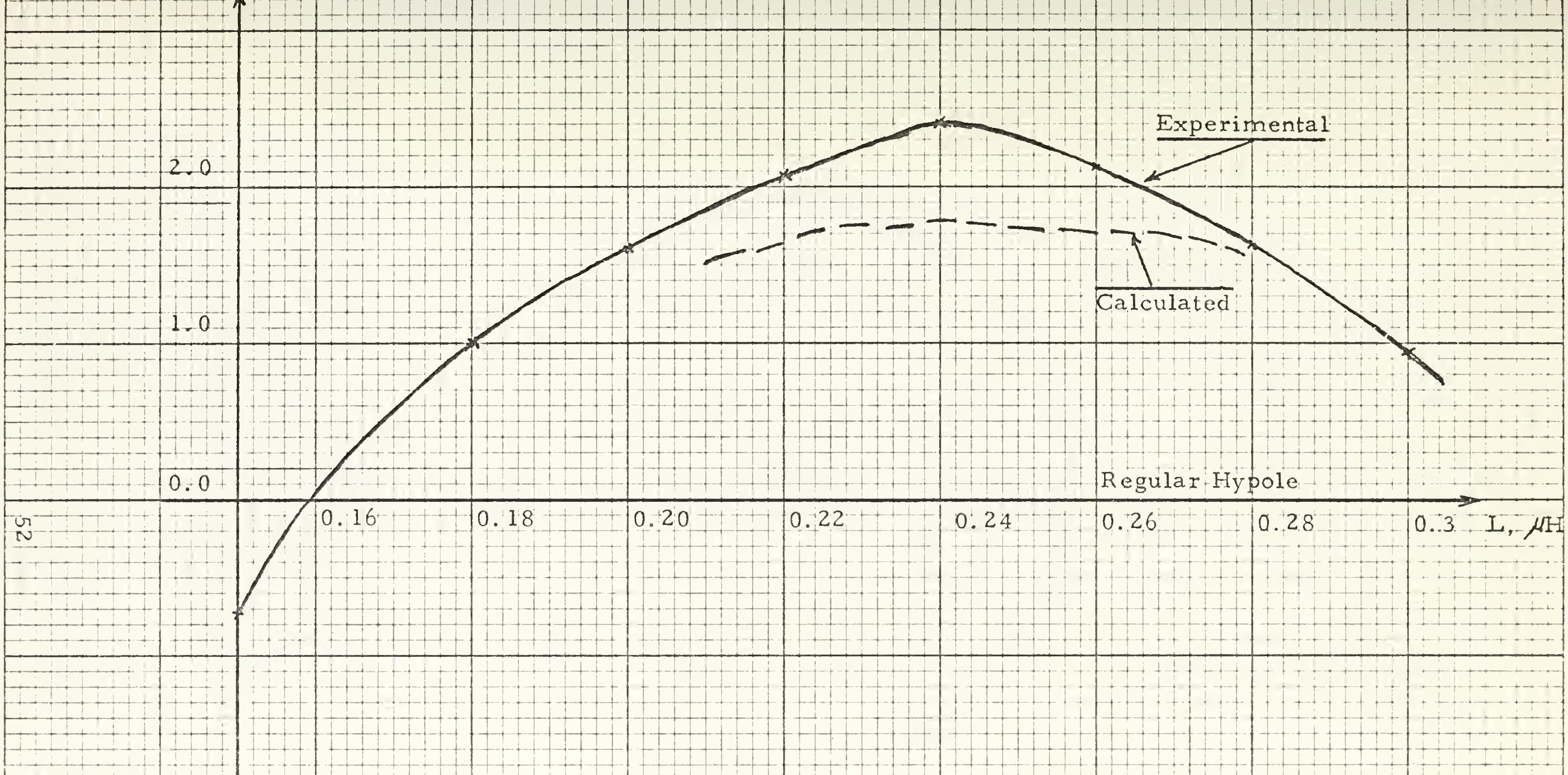


Figure 5-3
Gain of the Extended Hypole Over Regular Hypole vs. Inductance
Height Above the Ground Plane 8 Inches
Element Spacing One Inch

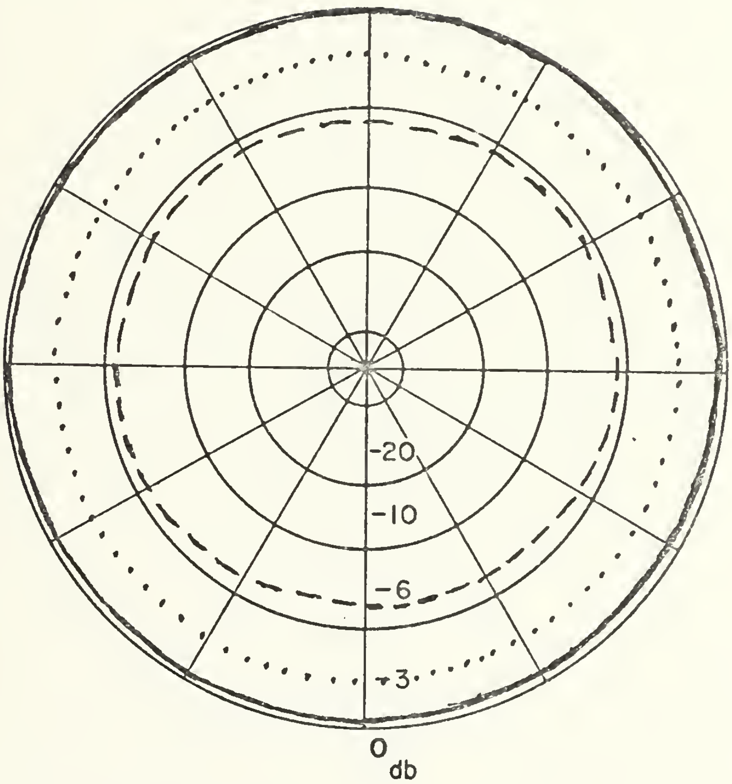


Figure 5-4
Measured Far Field Radiation Pattern of the Hypole and Extended Hypole
Height Above the Ground Plane 8 Inches
Element Spacing: 0.5 Inch
Extended Gain Hypole : Solid Curve
Half-Wave Dipole (Free Space) : Dotted Curve
Hypole : Broken Curve

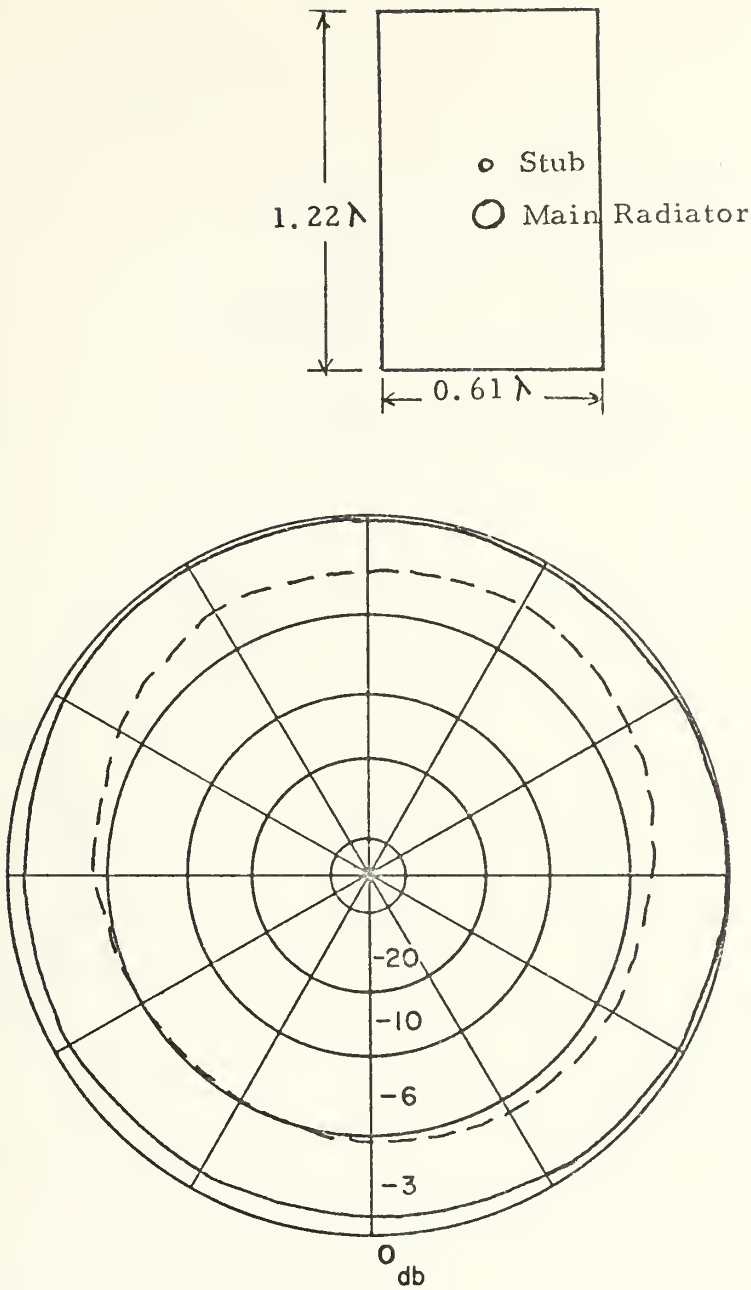
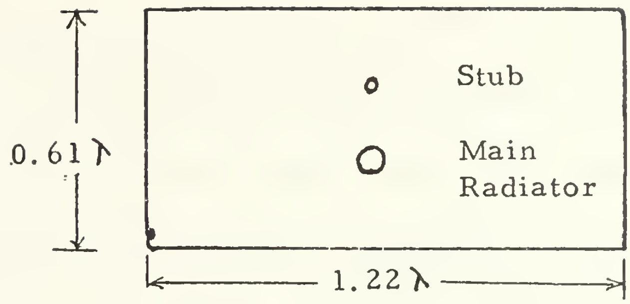


Figure 5-5
Measured Far Field Radiation Pattern
Hypole Oriented Along Major Axis
Height Above the Ground Plane 8 Inches
Element Spacing 1 Inch
Extended Hypole : Solid Curve
Hypole : Broken Curve



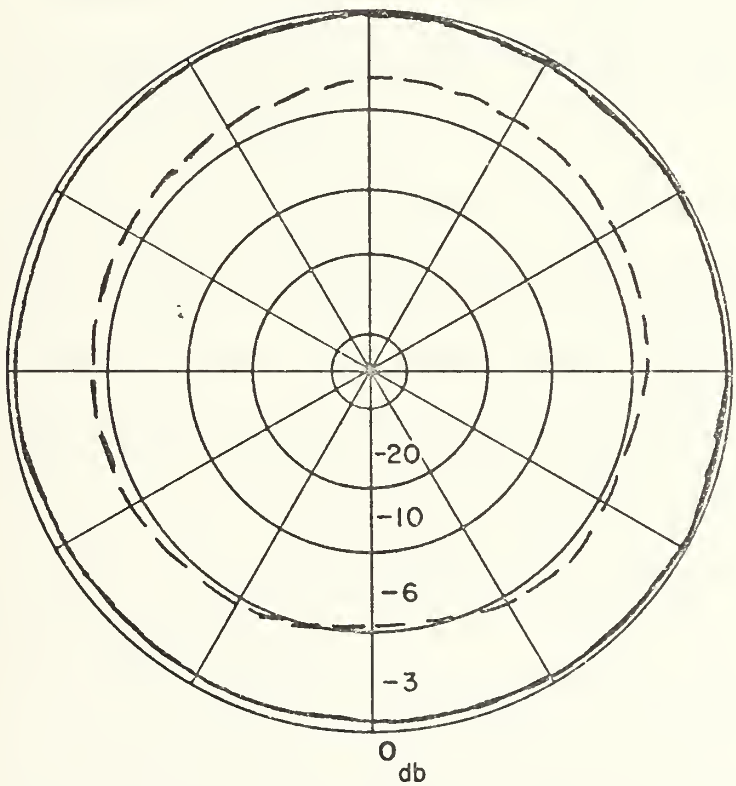


Figure 5-6
Measured Far Field Radiation Pattern
Hypole Oriented Along Minor Axis
Height above the Ground Plane 8 Inches
Element Spacing One Inch
Extended Hypole : Solid Curve
Hypole : Broken Curve

VI. CONCLUSIONS AND RECOMMENDATIONS

The Hybrid dipole "Hypole" antenna operating above the ground plane exhibits characteristics similar to that of a half-wave dipole in free space. The Hypole antenna uses a quarter wave stub to cancel the undesired radiation from the lower third of a three quarter wavelength radiating element. The result is a half-wave dipole located above and isolated from the effects of the finite ground plane which is usually available in land mobile and shipboard communication systems.

The computer program, based on thin wire approximations, used for the Hypole antenna analysis provides a handy and useful insight into its performance characteristics. The results obtained from the model provide an accurate method of predicting the far field radiation pattern of the antenna as well as its input impedance as a function of frequency and its physical geometry. The model is limited, however, in its ability to accurately predict field strength.

The extended gain Hypole uses an additional half-wavelength radiating element in series with the main radiating element of the Hypole antenna. An inductance is placed between these two elements to introduce the required phase shift resulting in two half-wave series elements with in-phase current distributions. The extended gain Hypole antenna provides a significant gain (typically 2.7DB) over that of the Hypole. The resultant

far field pattern also exhibits a more uniform omnidirectional pattern in the plane of the horizon.

To gain further insight into the operation of the Hypole and extended gain Hypole antennas, it is recommended that a suitable current probe be constructed to measure the magnitude and phase of the currents flowing on these antennas. The result of this investigation could then be compared with currents provided by using the ASAP program. Measurements of surface currents on the ground plane would provide valuable information of the interaction of the limited size ground plane on antenna performance.

APPENDIX A

PREDICTED VALUES OF HYPOLE ANTENNA INPUT IMPEDANCE

TABLE I

PREDICTED INPUT IMPEDANCES OF THE HYPOLE ANTENNA ON THE GROUND PLANE

ELEMENT SPACING 0.5 INCH

FREQ	CORRECTION FACTOR		
Mhz	0	2%	4%
420	18.5 - j 54.5	17.1 - j 44.4	16.0 - j 34.7
425	17.8 - j 48.5	16.5 - j 38.5	15.5 - j 28.7
430	17.0 - j 42.6	15.9 - j 32.5	15.0 - j 22.7
435	16.4 - j 36.7	15.4 - j 26.6	14.6 - j 16.8
440	15.9 - j 30.9	15.0 - j 20.8	14.3 - j 10.8
445	15.4 - j 25.2	14.6 - j 15.0	14.1 - j 4.9
450	15.0 - j 19.5	14.3 - j 9.2	13.9 + j 1.0
455	14.7 - j 13.8	14.1 - j 3.4	13.8 + j 7.0
460	14.4 - j 8.1	14.0 + j 2.5	13.8 + j 13.0
465	14.2 - j 2.3	13.9 + j 8.3	13.8 + j 19.1
470	14.0 + j 3.4	13.9 + j 14.3	14.0 + j 25.2
475	14.0 + j 9.1	14.0 + j 20.2	14.2 + j 31.5
480	14.0 + j 14.9	14.1 + j 26.3	14.6 + j 37.8

TABLE II

PREDICTED INPUT IMPEDANCES OF THE HYPOLE ANTENNA ON THE GROUND PLANE

ELEMENT SPACING 1 INCH

FREQ	CORRECTION FACTOR		
Mhz	0	2%	4%
420	34.6 - j 55.8	31.8 - j 41.4	29.5 - j 27.5
425	33.0 - j 46.7	30.5 - j 32.4	28.4 - j 18.7
430	31.6 - j 37.8	29.3 - j 23.7	27.5 - j 9.9
435	30.4 - j 29.2	28.4 - j 15.1	26.8 - j 1.2
440	29.3 - j 20.6	27.5 - j 6.5	26.2 + j 7.4
445	28.4 - j 12.2	26.9 + j 2.0	25.8 + j 16.0
450	27.6 - j 3.8	26.4 + j 10.4	25.6 + j 24.7
455	27.0 + j 4.5	26.1 + j 18.9	25.5 + j 33.4
460	26.5 + j 12.8	25.8 + j 27.4	25.6 + j 42.2
465	26.2 + j 21.1	25.8 + j 36.0	25.9 + j 51.1
470	26.1 + j 29.4	25.9 + j 44.6	26.4 + j 60.1
475	26.1 + j 37.8	26.3 + j 53.3	27.1 + j 69.4
480	26.3 + j 46.3	26.8 + j 62.2	28.1 + j 78.8

TABLE III

PREDICTED INPUT IMPEDANCES OF THE HYPOLE ANTENNA 4 INCHES ABOVE THE GROUND PLANE

ELEMENT SPACING 0.5 INCH

FREQ	CORRECTION FACTOR		
Mhz	0	2%	4%
420	29.0 - j 56.4	24.4 - j 43.4	21.0 - j 31.7
425	25.9 - j 48.2	22.3 - j 35.8	19.5 - j 27.4
430	23.5 - j 40.5	20.5 - j 28.5	18.2 - j 17.4
435	21.6 - j 33.1	19.2 - j 21.5	17.3 - j 10.6
440	20.1 - j 26.1	18.1 - j 14.7	16.5 - j 3.9
445	18.9 - j 19.3	17.2 - j 8.0	15.8 + j 2.7
450	17.9 - j 12.7	16.4 - j 1.5	15.3 + j 9.1
455	17.1 - j 6.2	15.9 + j 4.9	14.8 + j 15.5
460	16.5 + j 0.1	15.4 + j 11.2	14.5 + j 21.9
465	15.9 + j 6.4	15.0 + j 17.5	14.2 + j 28.3
470	15.5 + j 12.6	14.6 + j 23.8	14.0 + j 34.7
475	15.1 + j 18.8	14.4 + j 30.1	13.9 + j 41.2
480	14.8 + j 25.0	14.2 + j 36.5	13.8 + j 47.7

TABLE IV

PREDICTED INPUT IMPEDANCES OF THE HYPOLE ANTENNA
4 INCHES ABOVE THE GROUND PLANE

ELEMENT SPACING 1 INCH

FREQ	CORRECTION FACTOR		
Mhz	0	2%	4%
420	48.2 - j 67.4	41.3 - j 48.2	36.2 - j 30.7
425	43.6 - j 55.0	38.0 - j 36.7	33.8 - j 19.8
430	40.0 - j 43.4	35.4 - j 25.8	31.9 - j 9.4
435	37.2 - j 32.4	33.4 - j 15.3	30.4 + j 0.7
440	34.9 - j 21.9	31.7 - j 5.2	29.2 + j 10.6
445	33.1 - j 11.8	30.3 + j 4.6	28.3 + j 20.3
450	31.6 - j 1.9	29.3 + j 14.3	27.5 + j 29.9
455	30.4 + j 7.7	28.4 + j 23.8	26.9 + j 39.5
460	29.4 + j 17.1	27.7 + j 33.2	26.4 + j 49.0
465	28.6 + j 26.4	27.3 + j 42.6	26.2 + j 58.6
470	28.0 + j 35.7	26.9 + j 52.0	26.0 + j 68.3
475	27.6 + j 44.9	26.6 + j 61.5	25.9 + j 78.0
480	27.3 + j 54.2	26.5 + j 71.1	25.9 + j 88.0

TABLE V

PREDICTED INPUT IMPEDANCES OF THE HYPOLE ANTENNA
6 INCHES ABOVE THE GROUND PLANE

ELEMENT SPACING 0.5 INCH

FREQ	CORRECTION FACTOR		
Mhz	0	2%	4%
420	21.4 - j 52.1	19.6 - j 40.1	18.1 - j 30.5
425	20.3 - j 45.1	18.7 - j 34.2	17.4 - j 23.8
430	19.3 - j 38.4	17.9 - j 27.6	16.8 - j 17.2
435	18.5 - j 31.8	17.3 - j 21.1	16.3 - j 10.7
440	17.8 - j 25.4	16.8 - j 14.6	15.9 - j 4.3
445	17.2 - j 19.0	16.3 + j 8.3	15.6 + j 2.1
450	16.8 - j 12.8	16.0 - j 2.0	15.4 + j 8.5
455	16.4 - j 6.6	15.7 + j 4.3	15.2 + j 14.9
460	16.1 - j 0.4	15.6 + j 10.5	15.1 + j 21.3
465	15.9 + j 5.7	15.4 + j 16.9	15.1 + j 27.9
470	15.7 + j 11.9	15.3 + j 23.2	15.1 + j 34.5
475	15.6 + j 18.1	15.3 + j 29.7	15.2 + j 41.2
480	15.5 + j 24.4	15.3 + j 36.2	15.3 + j 48.1

TABLE VI

PREDICTED INPUT IMPEDANCES OF THE HYPOLE ANTENNA
6 INCHES ABOVE THE GROUND PLANE

ELEMENT SPACING 1 INCH

FREQ	CORRECTION FACTOR		
Mhz	0	2%	4%
420	36.5 - j 58.1	33.6 - j 42.4	31.3 - j 27.4
425	34.7 - j 48.0	32.2 - j 32.6	30.2 - j 17.7
430	33.2 - j 38.2	31.1 - j 23.0	29.4 - j 8.2
435	32.0 - j 28.7	30.2 - j 13.6	28.7 + j 1.2
440	31.0 - j 19.4	29.4 - j 4.3	28.2 + j 10.5
445	30.2 - j 10.3	28.8 + j 4.9	27.8 + j 19.8
450	29.5 - j 1.2	28.4 + j 14.0	27.5 + j 29.1
455	29.0 + j 7.8	28.0 + j 23.2	27.3 + j 38.5
460	28.6 + j 16.7	27.8 + j 32.3	27.3 + j 48.0
465	28.3 + j 25.7	27.7 + j 41.6	27.4 + j 57.6
470	28.2 + j 34.7	27.7 + j 50.9	27.5 + j 67.4
475	28.1 + j 43.8	27.9 + j 60.4	27.8 + j 77.4
480	28.2 + j 53.0	28.1 + j 70.1	28.2 + j 87.7

TABLE VII

PREDICTED INPUT IMPEDANCES OF THE HYPOLE ANTENNA
8 INCHES ABOVE THE GROUND PLANE

ELEMENT SPACING ONE HALF INCH

FREQ	CORRECTION FACTOR		
Mhz	0	2%	4%
420	18.1-j 48.8	17.2-j 38.8	16.4-j 29.2
425	17.6-j 42.5	16.7-j 32.6	16.0-j 22.9
430	17.0-j 36.4	16.3-j 26.4	15.7-j 16.7
435	16.6-j 30.3	16.0-j 20.3	15.5-j 10.5
440	16.3-j 24.3	15.7-j 14.2	15.3-j 4.3
445	16.0-j 18.4	15.5-j 8.1	15.2+j 1.9
450	15.8-j 12.4	15.4-j 2.0	15.2+j 8.2
455	15.6-j 6.5	15.4+j 4.1	15.2+j 14.6
460	15.5-j 0.5	15.4+j 10.3	15.4+j 21.0
465	15.5+j 5.5	15.4+j 16.5	15.6+j 27.6
470	15.5+j 11.6	15.6+j 22.9	15.8+j 34.4
475	15.6+j 17.7	15.8+j 29.4	16.3+j 41.4
480	15.8+j 24.0	16.2+j 36.1	16.9+j 48.6

TABLE VIII

PREDICTED INPUT IMPEDANCES OF THE HYPOLE ANTENNA 8 INCHES ABOVE THE GROUND PLANE

ELEMENT SPACING ONE INCH

FREQ	CORRECTION FACTOR		
Mhz	0	2%	4%
420	31.4-j 51.8	29.9-j 38.1	28.6-j 24.6
425	30.5-j 42.9	29.1-j 29.2	28.0-j 15.7
430	29.7-j 34.2	28.6-j 20.4	27.6-j 6.8
435	29.1-j 25.6	28.1-j 11.7	27.3+j 2.0
440	28.5-j 17.1	27.7-j 3.1	27.1+j 10.9
445	28.1-j 8.6	27.5+j 5.6	27.0+j 19.8
450	27.9-j 0.1	27.4+j 14.3	27.0+j 28.8
455	27.7+j 8.3	27.3+j 23.0	27.0+j 38.0
460	27.6+j 16.9	27.4+j 31.9	27.4+j 47.3
465	27.6+j 25.5	27.6+j 41.0	27.8+j 56.9
470	27.7+j 34.2	27.9+j 50.2	28.4+j 66.8
475	27.9+j 43.1	28.3+j 59.7	29.1+j 77.0
480	28.3+j 52.2	29.0+j 69.5	30.1+j 87.7

APPENDIX B

COMPUTER DATA CARDS FOR MODELING THE HYPOLE AND THE EXTENDED GAIN HYPOLE ANTENNAS

```
C     THE FOLLOWING DATA CARDS ARE USED TO MODEL
C     THE HYPOLE ANTENNA USING THE ASAP PROGRAM
C     ANTENNA DESIGNED FOR 450 MHZ OPERATION
C     HEIGHT ABOVE THE GROUND PLANE 8 INCHES
C     SPACING OF THE ELEMENTS 1 INCH
C     CORRECTION FACTOR 2%
C
C
WIRE (RADIUS = .0016)
FREQ (450.)
DESC (1-2/2-3/3-4/4-5/5-6/6-7/7-8/4-9/9-10/10-11/11-12/12-13)
GEOM (0,0,0/0,0,.068/0,0,.135/0,0,.203/0,0.322/0,0,.322/0,0,.441/
     0,0.56/0,0.6792/0,0,-.0127,.203/0,-,0254,.203/0,-,0254,.255/
     0, .0254,.307/0,-.0254,.3596)
GROUND (HEIG = 0.0/PERF)
GENE (4,.5,+90/8,.5,-90)
OUTPUT (FARF = 90,90,0,360)
PLOT (FARF/THETA=90)
STOP
```

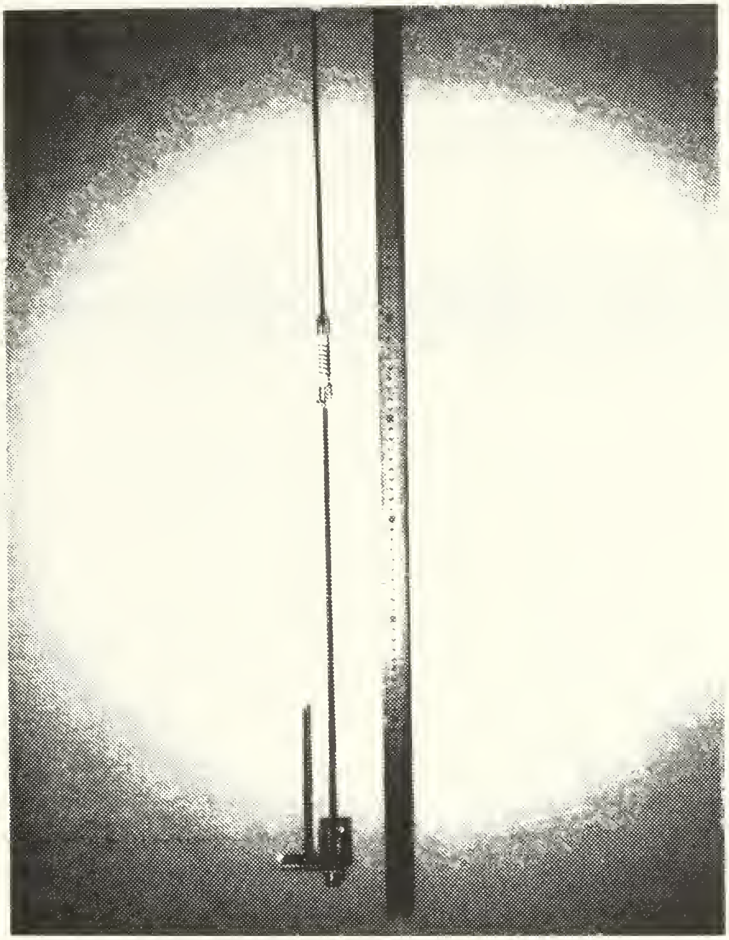
```
C     THE FOLLOWING DATA CARDS ARE USED TO MODEL
C     THE HYPOLE ANTENNA USING THE ASAP PROGRAM
C     ANTENNA DESIGNED FOR 450 MHZ OPERATION
C     HYPOLE ANTENNA OPERATING ON THE GROUND PLANE
C     A FINITE HEIGHT ABOVE THE GROUN D PLANE REQUIRED
C     FOR THE MODEL
C     SPACING OF THE ELEMENTS 1 INCH
C     CORRECTION FACTOR 2%
C
C
WIRE (RADIUS = 0.0016)
FREQ (450)
DESC (1-2/2-3/3-4/4-5/5-6/1-7/7-8/8-9/9-10/10-11)
GEOM (0,0,0/0,-,0127,0/0,-.0254,0/0,-.0254.051/0,-,0254,.102/
      0,.0254,.1564/0,0,.187/0,0,.28/0,0,.373/0,0,.4760)
GROUND (HEIG = 0.001/PER F)
GENE (1,.5,-90/6,.5,+90)
OUTPUT (FARF = 90,90,0,360)
PLOT (FARF/THETA=90)
STOP
```

```
C     THE FOLLOWING DATA CARDS ARE USED WHEN
C     MODELING THE EXTENDED GAIN HYPOLE ANTENNA
C     USING THE ASAP PROGRAM
C     ANTENNA DESIGNED FOR 450 MHZ OPERATION
C     HEIGHT ABOVE THE GROUND PLANE 8 INCHES
C     SPACING OF THE ELEMENTS 1 INCH
C     CORRECTION FACTOR 2%
C     INDUCTIVE REACTANCE 700 OHMS
C
C
WIRE (RADIUS = .0016)
FREQ (450.)
DESC (1-2/2-3/3-4/4-5/5-6/6-7/7-8/8-9/9-10/10-11/11-12/12-13/
      4-14/14-15/15-16/16-17/17-18)
GEOM (0,0,0/0,0,.068/0,0,.135/0,0,.203/0,0,.322/0,0,.441/0,0,.56/
      0,0,.6792/0,0,.7142/0,0,.7492/0,0,.856/0,0,.962/0,0,/.0688/
      0,-0127,.203/0,-.0,-.0254,.255/0,-.0254,.307/0,-.0254,.3596)
GROUND (HEIG = 0.0/PERF)
GENE (4,.5,+90/13,.5,-90)
LOAD (9,700,+90)
OUTPUT (FARF = 90,90,0,360)
PLOT (FARF/THETA =90)
STOP
```

APPENDIX C

PHOTOGRAPHS OF THE HYPOLE AND THE EXTENDED GAIN HYPOLE ANTENNAS

THE HYPOLE ANTENNA



THE EXTENDED GAIN HYPOLE ANTENNA

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